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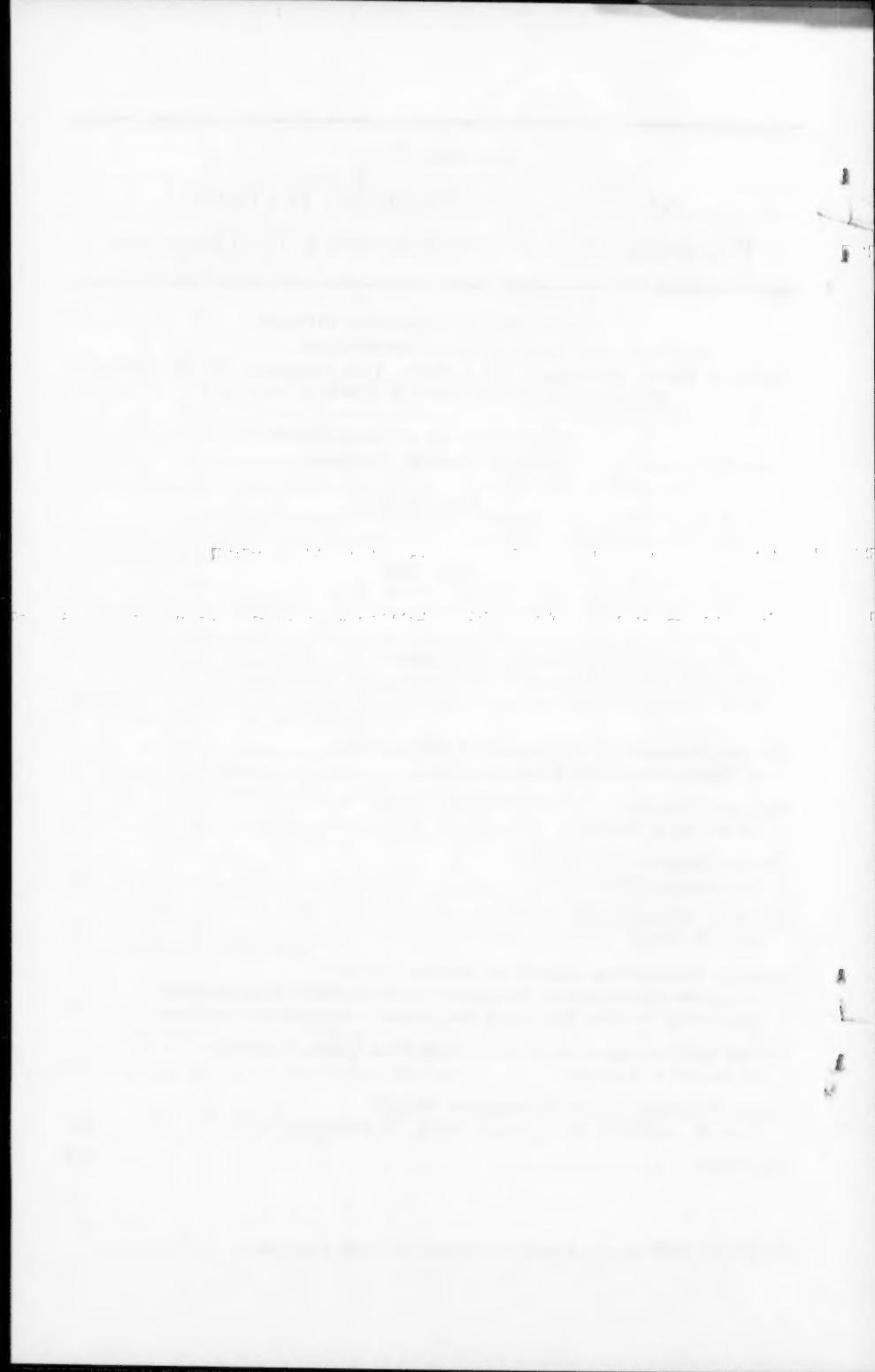
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DESIGN PRINCIPLES FOR UNDERGROUND SALT CAVITIES^a

By Shosei Serata¹ and Ernest Gloyna,² M. ASCE

SYNOPSIS

Theoretical equilibrium relationships as substantiated by experimental studies are presented here for use in the design of salt cavities. Also included are studies on reduction of cavity volume, development of the plastic zone, and stress redistribution around the cavity as functions of cavity depth, strength of salt, and physico-chemical effects of the waste.

INTRODUCTION

The ultimate disposal of radioactive waste in quantity has become one of the most important problems of this age. The object of this paper is to present design principles for the construction of salt cavities as containers for high-level radioactive waste.

The theoretical investigations of spherical and cylindrical cavities included analysis of elastic stress, thermal stress, development of the plastic zone, reduction of cavity volume and the resulting stress redistribution around the cavities. The theoretical analyses have demonstrated that the structural equilibrium relations of a salt cavity can be established in relation to cavity temperature, structural loading condition, and cavity volume reduction.

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^a Presented at the April 1959 Nuclear Engineering and Science Conference in Cleveland, Ohio.

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In the laboratory, the fundamental properties of salt as well as the various factors affecting these properties were investigated. By using a model salt cavity, the volume reduction in connection with the development of the plastic zone was studied. Measurements of creep in the Grand Saline salt mine were made and the results seem to agree with the theoretical and experimental conclusions.

ELASTIC STRESS ANALYSIS

Depending on the geometry, the stability of a salt cavity can be studied using the theory of elasticity when the depth of the cavity does not exceed a value of approximately 500 ft to 1,000 ft. The stress condition around a cavity can be mathematically determined for cavities of simple forms like a sphere, cylinder, or elliptical tunnel. For cavities of irregular form, the theory of photoelasticity can be successfully applied.³ By using both theories, the effects of depth, size, shape, number, and geometry of cavity opening upon the elastic stress distribution are determined.

The initial stress naturally existing in any underground formation before an opening is made is primarily determined by two factors, the overburden load and the Poisson's ratio of the formation, as follows:

in which v is Poisson's ratio, σ_y denotes the lateral stress, and σ_z is the vertical stress or overburden load.

Experimental determination of Poisson's ratio is necessary to determine natural stress distributions in salt. The results of both the laboratory experiments and the calculations on seismic data are in agreement. The value of Poisson's ratio is approximately 0.5 at a depth greater than 300 ft. The stress distribution in the salt therefore approximates that found under hydrostatic load.

Therefore, due to the overburden load, cavities created at a depth of 300 ft or above will be subject to a non-hydrostatic external stress condition; cavities below a depth of 300 ft will be subject to a hydrostatic stress condition. If some horizontal tectonic pressure is existing in the formation, this tectonic pressure should be superimposed over the above-mentioned stress conditions as illustrated in Fig. 1.

By creation of a cavity in an initially stressed salt formation, maximum and minimum stresses and maximum shearing stress always appear on the boundary around the cavity opening. The magnitude of these critical stresses depends on the form of the cavity, as illustrated in Fig. 2. In the diagram, the stress distribution around circular and rectangular openings is shown for the three fundamental initial stress conditions, hydrostatic, non-hydrostatic, and unidirectional.⁴

As seen in Fig. 2, the stress distribution is affected by the form of the opening as well as by the initial stress condition. However, no tensile stress occurs

³ "Design by Photoelasticity," by R. B. Heywood, Campman & Hall, Ltd., London, 1952.

⁴ "Stress Around Mine Openings in Some Simple Geological Structures," by R. D. Caudle and G. B. Clark, Engrg. Experiment Sta. Bulletin No. 430, Univ. of Illinois, 52, No. 69, May, 1955.

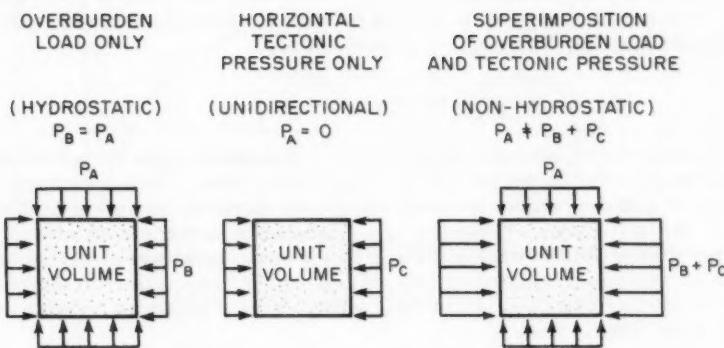


FIG. 1.—INITIAL STRESS CONDITIONS IN SALT FORMATION.

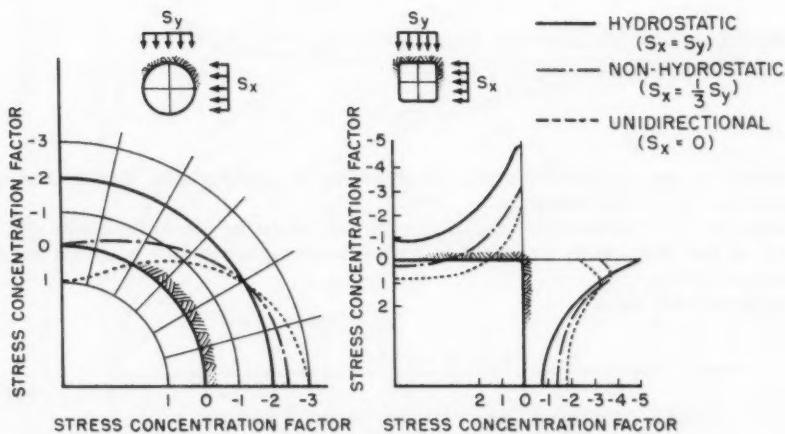


FIG. 2.—DISTRIBUTION OF CRITICAL STRESS AROUND CIRCULAR AND SQUARE TUNNEL OPENINGS.

curs around the cavity unless the ratio of the major to minor initial principal stresses exceeds three. In reality, therefore, significant tensile stress is not probable around any form of salt cavity.

The effect of cavity size on stress distribution can be illustrated by the theoretical analysis of stress distribution around a spherical cavity, as plotted in Fig. 3. In an initially stressed media the stress distribution is directly proportional to the size of the newly formed opening. The maximum stress always appears on the boundary of the cavity in a tangential direction, the minimum stress appearing on the boundary in a radial direction. However, the stresses are independent of the cavity size and constant at a given cavity depth. The stress distribution around cavities of irregular form can also be investigated by using the theory of photoelasticity.

PLASTICITY ANALYSIS

Creep deformation of a salt cavity becomes significant when the cavity depth exceeds about 1,000 ft or the cavity temperature rises. In such a case, the plasticity of salt is probably the most influential factor on the structural stability of the salt cavity. Whenever the maximum shearing stress around the cavity exceeds a certain value, the salt starts to creep rather than fracture. Because of this creep, the salt cavity will never collapse under an increased loading condition. Addition of thermal stress merely produces a further extension of the plastic zone.

The development of the plastic zone in spherical and cylindrical cavities can be mathematically analyzed by introduction of the octahedral shearing stress (Eq. 2) into the following differential equation defining the stress equilibrium around the cavity:⁵

Octahedral shearing stress:

$$\tau_o = \frac{1}{3} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \quad \dots \dots \dots (2)$$

Stress equilibrium around a spherical cavity:

$$\frac{d\sigma_r}{dr} + \frac{2}{r} (\sigma_r - \sigma_t) = 0 \quad \dots \dots \dots (3)$$

in which σ_1 , σ_2 , σ_3 are the principal stresses, σ_r is the radial stress, and σ_t denotes the tangential stresses.

Solution of the differential equation with respect to the actual boundary condition of the salt cavity gives the following stress-distribution equation for a spherical cavity:

In the plastic zone:

$$\left. \begin{aligned} \sigma_r &= -p_i - 2 \sigma_o \ln \frac{r}{a} \\ \sigma_t &= -p_i - 2 \sigma_o \left(\frac{1}{2} + \ln \frac{r}{a} \right) \end{aligned} \right\} \quad \dots \dots \dots (4a)$$

⁵ "Plasticity," by A. Nadai, McGraw-Hill Book Co., New York, 1931.

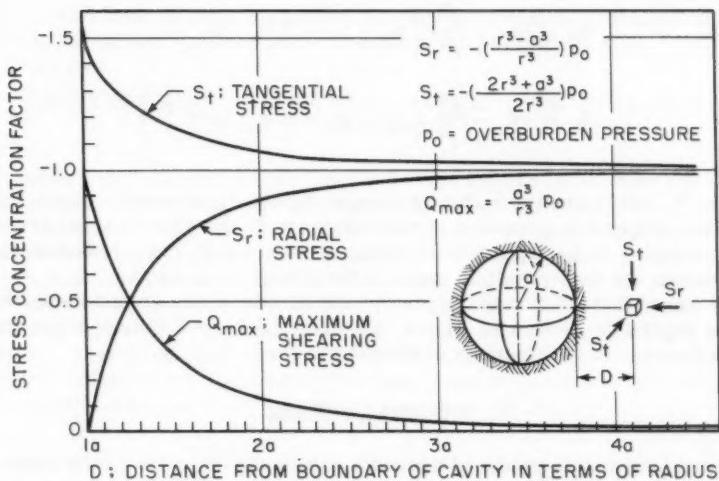


FIG. 3.—STRESS CONCENTRATION AROUND SPHERICAL CAVITY.

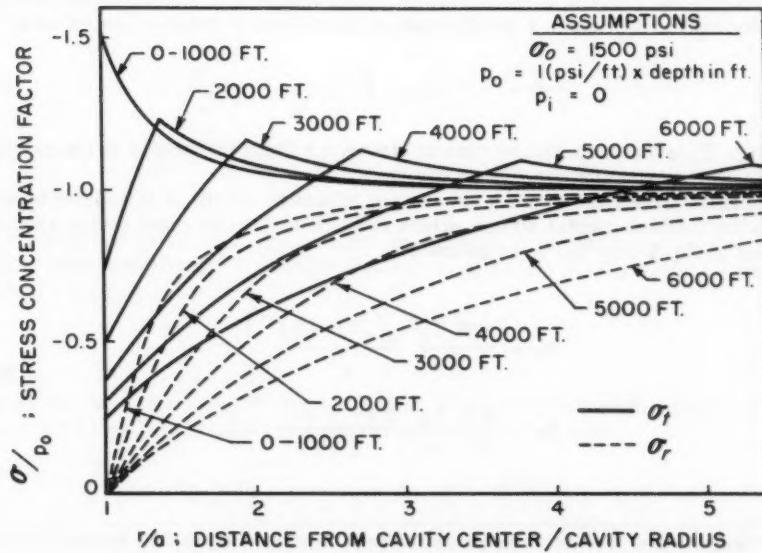


FIG. 4.—STRESS DISTRIBUTION IN PLASTIC AND ELASTIC ZONES AROUND SPHERICAL SALT CAVITY AT VARIOUS DEPTHS.

In the elastic zone:

$$\left. \begin{aligned} S_r &= -p_0 + \frac{\rho^3}{r^3} \left(p_0 - p_i - 2 \sigma_0 \ln \frac{\rho}{a} \right) \\ S_t &= -p_0 - \frac{\rho^3}{r^3} \left(p_0 - p_i - 2 \sigma_0 \ln \frac{\rho}{a} \right) \end{aligned} \right\} \quad \dots \dots \dots \quad (4b)$$

in which S_r and S_t are the radial and tangential elastic stresses, respectively; p_0 is the overburden pressure of the cavity, p_i denotes the internal pressure of the cavity, σ_0 is the equivalent yielding stress of salt, r is a radial distance, a represents the cavity radius, and ρ is the plastic front radius.

The stress distribution in the plastic and elastic zones around the cavity at various depths is plotted in Fig. 4, showing the radical change of the stress distribution due to development of the plastic zone.

THERMAL STRESS

Thermal stress is produced around a salt cavity when the cavity temperature rises above the surrounding earth temperature. The nature of the temperature rise in the cavity depends on three major factors: the nature and condition of the waste, the geometry of the cavity, and the thermal property of the salt.⁶

By applying Fourier's conduction equation, temperature distribution around a spherical cavity, under a steady state of heat flow, is obtained as follows:⁷

$$T_r = \frac{a}{r} T_c \quad \dots \dots \dots \quad (5)$$

in which T_r is the temperature rise at distance r from the center of the cavity, and T_c is the temperature rise in the cavity.

Thermal stress distribution around the spherical cavity is calculated by introducing the fundamental stress-strain relation and the thermal strain as calculated in Eq. 5 into Eq. 3, as follows:⁸

$$\left. \begin{aligned} S_r &= \frac{\alpha E T_c}{1 - \mu} \frac{a(r^2 - a^2)}{r^3} \\ S_t &= \frac{\alpha E T_c}{1 - \mu} \frac{a(r^2 + a^2)}{2 r^3} \end{aligned} \right\} \quad \dots \dots \dots \quad (6)$$

⁶ "Temperature Rise in Underground Storage Sites for Radioactive Wastes," by R. S. Schechter and E. F. Glynna, Industrial and Engineering Chemistry, 1958.

⁷ "Heat Conduction with Engineering and Geological Applications," by L. R. Ingersoll, O. J. Zobel and A. C. Ingersoll, McGraw-Hill Book Co., New York, 1948.

⁸ "Theory of Elasticity," by S. Timoshenko and J. N. Goodier, McGraw-Hill Book Co., New York, 1951.

The actual thermal stress distribution due to elevated temperature around a spherical salt cavity can be calculated by introducing the proper values of the three coefficients for the salt, namely, Young's modulus, Poisson's ratio and the coefficient of linear expansion into Eq. 6. In Fig. 5, the distribution is plotted by using these coefficients determined in the laboratory.

DEVELOPMENT OF STRUCTURAL EQUILIBRIUM EQUATIONS FOR DESIGNING CAVITY

To design an underground salt cavity for the storage of reactor fuel waste, the relation among cavity temperature rise, structural loading, and cavity volume reduction must be established first. Such a relation is obtained by correlating the effects of elastic stress, thermal stress, development of plastic zone, and the thermal expansion of the salt.

The stress distribution around a cavity with elevated temperature can be determined by superimposing the thermal stress over the plastic and elastic stresses. It is found that the stress distribution equation in the plastic zone (Eq. 4a) is not affected by temperature rise. The stress distribution equation for the elastic zone around a spherical cavity then becomes:

$$S_r = -p_0 + \frac{\rho^3}{r^3} \left[p_0 - p_i - 2 \sigma_0 \ln \frac{\rho}{a} + \frac{\alpha E T_c}{1 - \mu} \frac{a(\rho^2 - a^2)}{\rho^3} \right] - \frac{\alpha E T_c}{1 - \mu} \frac{a(r^2 - a^2)}{r^3} \quad \dots \dots \dots \quad (7a)$$

$$S_t = -p_0 + \frac{\rho^3}{2 r^3} \left[p_0 - p_i - 2 \sigma_0 \ln \frac{\rho}{a} + \frac{\alpha E T_c}{1 - \mu} \frac{a(\rho^2 - a^2)}{\rho^3} \right] - \frac{\alpha E T_c}{1 - \mu} \frac{a(\rho^2 - a^2)}{\rho^3} \quad \dots \dots \dots \quad (7b)$$

The condition existing at the borderline between the plastic and elastic zone can be expressed by Eq. 8, and by substitution of Eq. 7 into Eq. 8, it is possible to solve for ρ .

$$S_r - S_t = \sigma_0 \quad \dots \dots \dots \quad (8)$$

Thus, the equation describing the plastic front is obtained in relation to the structural loading condition and the cavity temperature rise.

$$\frac{p_0 - p_i}{\sigma_0} = 2 \ln \frac{\rho}{a} + \frac{2}{3} - \frac{2}{3} \frac{\alpha E T_c}{\sigma_0(1 - \mu)} \frac{a}{\rho} \quad \dots \dots \dots \quad (9)$$

Although Eq. 9 seems to be complex, the function which it represents can be used readily if properly plotted, because it is essentially composed of the following three factors:

$$\text{Factor of structural loading: } X = \frac{p_0 - p_i}{\sigma_0}$$

$$\text{Factor of plastic front radius: } Y = \frac{p}{a}$$

$$\text{Factor of temperature effect: } Z = \frac{\rho E T_c}{\sigma_0 (1 - \mu)}$$

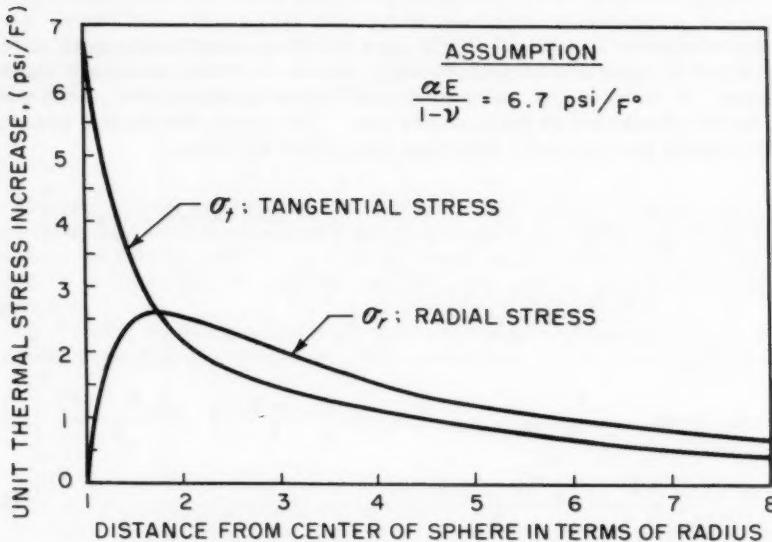


FIG. 5.—DISTRIBUTION OF UNIT THERMAL STRESS INCREASE AROUND SPHERICAL SALT CAVITY PER UNIT TEMPERATURE RISE IN CAVITY.

Since the Z-value is constant at any given temperature, Eq. 9 can best be plotted on an X-Y diagram as shown in Fig. 6, using the following assumptions:

$$\frac{\alpha E}{1 - \mu} = 6.7 \text{ psi per } ^{\circ}\text{F}$$

- $\sigma_0 = 1,500 \text{ psi}$ in temperature range up to 300° F
- $= 1,300 \text{ psi}$ in temperature range from 300° F to 500° F
- $= 1,000 \text{ psi}$ in temperature range from 500° F to 800° F
- $= 800 \text{ psi}$ in temperature range from 800° F to $1,100^{\circ} \text{ F}$
- $= 600 \text{ psi}$ in temperature range from $1,100^{\circ} \text{ F}$ to $1,475^{\circ} \text{ F}$

As seen in Fig. 6, a plastic zone will develop in a spherical cavity without any structural stress whenever cavity temperature is elevated over 800° F. Furthermore, the development of a plastic zone is much larger around a cylindrical cavity than a spherical one, with a rise in cavity temperature.

The amount of cavity volume reduction due to elevated temperature and the plastic flow of salt is calculated for both spherical and cylindrical cavities. Cavity volume is reduced by the thermal expansion of salt in the plastic zone, resulting in the plastic flow of the expanded salt into the cavity. The relation among the cavity temperature rise, the factor of plastic front radius, and cavity volume reduction is obtained by equating the salt expanded into the cavity with the cavity volume reduction.

In a spherical cavity:

$$\frac{p}{a} = \sqrt{\frac{2}{9 \alpha T_c} (1 - \zeta) + 1} \dots \dots \dots \quad (10)$$

in which ζ is the ratio of reduced cavity volume to the original volume, $1 - \zeta$ denotes the rate of cavity volume reduction, and α is the coefficient of the linear expansion of salt.

Under a steady heat flow from spherical cavities, a direct relationship between the factor of structural loading and the ultimate reduction of cavity volume, with any given temperature rise, can be obtained by eliminating the factor p/a from Eqs. 9 and 10.

In the case of a spherical cavity, the relation is found as:

$$\frac{p_o - p_i}{\sigma_o} = \ln \left[\frac{2(1 - \zeta)}{9 \alpha T_c} + 1 \right] + \frac{2}{3} - \frac{2}{3} \frac{\alpha E T_c}{\sigma_o(1 - \mu)} \sqrt{\frac{9 \alpha T_c}{9 \alpha T_c + 2(1 - \zeta)}} \dots \dots \dots \quad (11)$$

In the case of a cylindrical cavity, the relation is found from an identical derivation as:

$$1 - \zeta = 3 \alpha T_c (A e^B - 1.072) \dots \dots \dots \quad (12)$$

in which

$$A = 0.928 - \frac{B}{13.8} \dots \dots \dots \quad (13a)$$

$$B = \frac{2 \left(\frac{p_o - p_i}{\sigma_o} \right) + 0.928 \left[\frac{\alpha E T_c}{\sigma_o(1 - \mu)} \right] \frac{2}{\sqrt{3}}}{\frac{2}{\sqrt{3}} + 0.072 \left[\frac{\alpha E T_c}{\sigma_o(1 - \mu)} \right]} \dots \dots \dots \quad (13b)$$

To determine an allowable temperature rise in a given cavity, Eqs. 11 and 12 can be utilized. The equations are plotted in Fig. 7, showing the relations of structural loading, maximum allowable temperature rise in a cavity, and reduction of cavity volume at equilibrium.

These analyses demonstrate the fact that a salt cavity will close completely when plastic flow occurs due to increased temperature. The closure will oc-

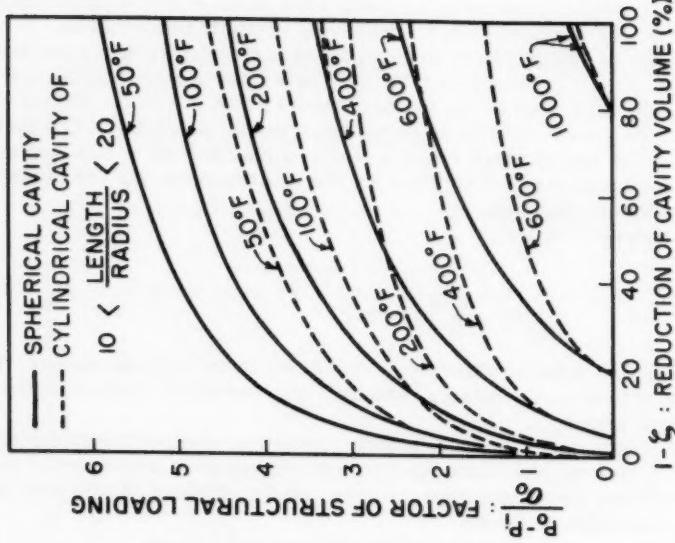


FIG. 7.—RELATION BETWEEN ULTIMATE REDUCTION OF CAVITY VOLUME AND STRUCTURAL LOADING WITH VARIOUS TEMPERATURE RISES IN CAVITY.

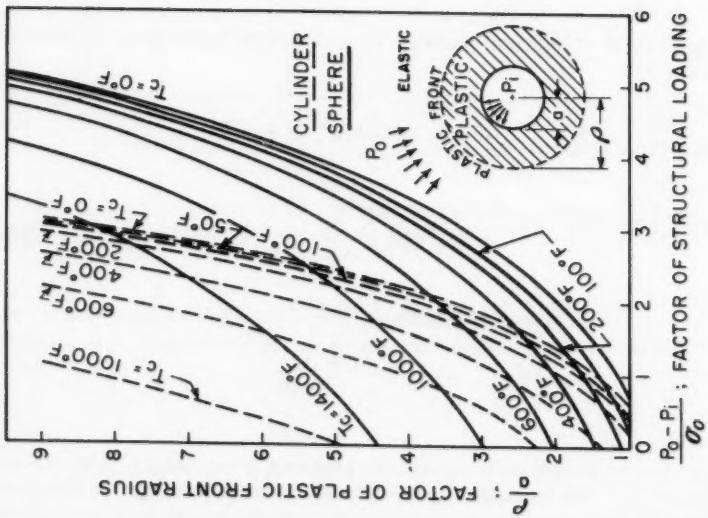


FIG. 6.—DEVELOPMENT OF PLASTIC ZONE AROUND SPHERICAL AND CYLINDRICAL CAVITIES WITH VARIOUS TEMPERATURE RISES.

cur before the cavity temperature reaches the melting point of salt (1,475° F.). Thus, cavity volume reduction due to elevated temperature can become a practical limitation. Therefore, the cavity can be successfully used for waste disposal if the cavity temperature rise can be controlled.

The ultimate structural equilibrium of an irregularly shaped cavity can be approximated by comparisons with the ideal spherical and cylindrical cavities. A cavity of irregular form would probably be as stable as a cavity of ideal form, since geometrical irregularities will not produce higher stress concentration because of the plastic nature of salt.

STRUCTURAL PROPERTY OF SALT

For application of the analytical theory of salt cavity equilibrium (Eqs. 11 and 12), various structural coefficients of salt have to be determined in the laboratory. In addition to the fundamental properties of salt, various factors affecting salt are investigated regarding reactor fuel waste storage in the salt cavity. The testing apparatus used is shown in Figs. 8, 9, 14, 17, 18, 20, and 21.

Consistent compression test results can be obtained only when the end friction effect of the salt specimen is eliminated. By using a specially developed standardized test procedure, the following fundamental properties of the aggregate salt from the Grand Saline salt mine were determined:

The maximum compressive stress	2,300 psi
with the standard deviation	200 psi
The 0.5% yielding stress	2,000 psi
Young's Modulus	0.14 x 10 ⁶ psi
with the standard deviation	0.03 x 10 ⁶ psi
Poisson's ratio	
with the compressive stress up to 300 psi	0.25 - 0.5
with the compressive stress over 300 psi	0.5

There is a wide variation in the previously reported figures regarding the fundamental properties of salt. These discrepancies are probably due to inconsistent testing procedures used by the various investigators.

The total creep of salt consists of instantaneous, transient, and steady state movements. It can be formulated with respect to time:

$$\epsilon_0 = \alpha + \beta \log t + \gamma t \dots \dots \dots \quad (14)$$

in which ϵ_0 is the total creep, α_0 denotes the instantaneous creep, β is the coefficient of transient creep, and γ represents the coefficient of steady state creep.

Heat has the greatest effect upon the structural property of salt. The creep rate of salt is increased 75 times by a temperature increase of 80°F to 770°F. This means that a salt cavity reaches its ultimate structural equilibrium much faster if the cavity temperature is elevated. The equivalent yielding stress of salt is reduced to 1,000 psi with temperature increase of 80°F to 500°F; thereafter, the equivalent yielding stress remains nearly constant at around 1,000 psi as the temperature approaches the melting point of salt. Heat effects Young's modulus and the coefficient of linear expansion of salt very slightly. The specimens tested are shown in Figs. 15, 16 and 19.

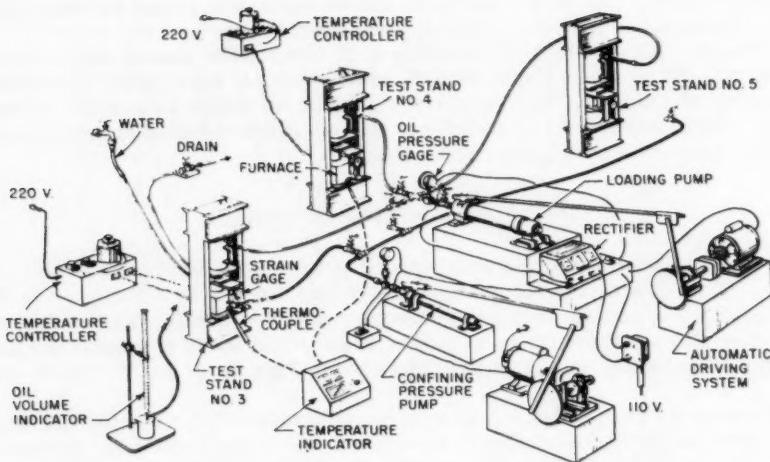


FIG. 8.—ASSEMBLY OF COMPREHENSIVE TEST DEVICE.

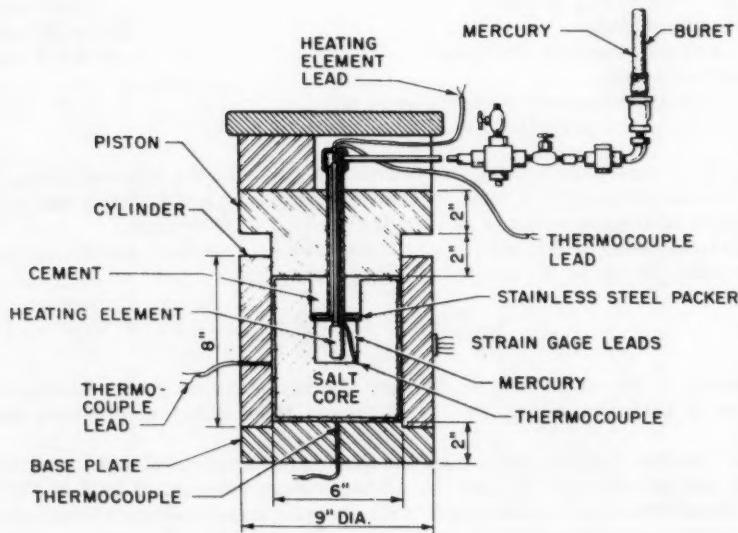


FIG. 9.—CROSS SECTION OF TEST CYLINDER.

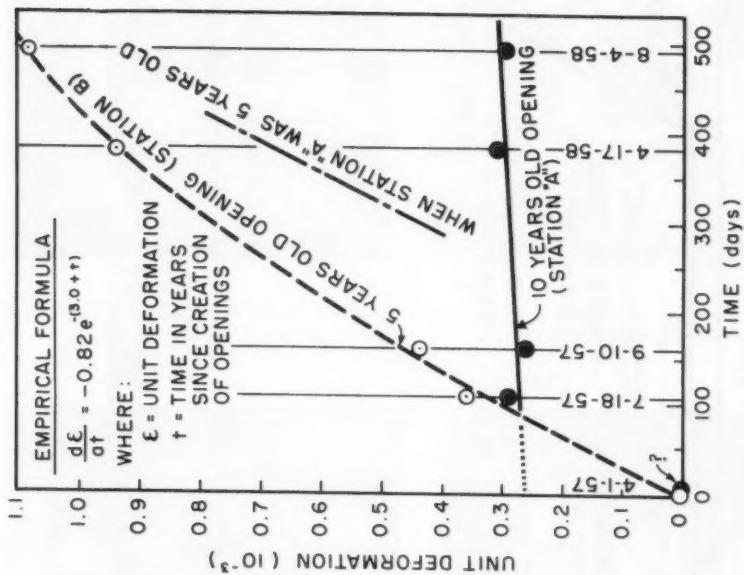


FIG. 11.—CREEP CLOSURE RATE OF TUNNEL OPENINGS IN GRAND SALINE SALT DOME AT DEPTH OF 700 FEET.

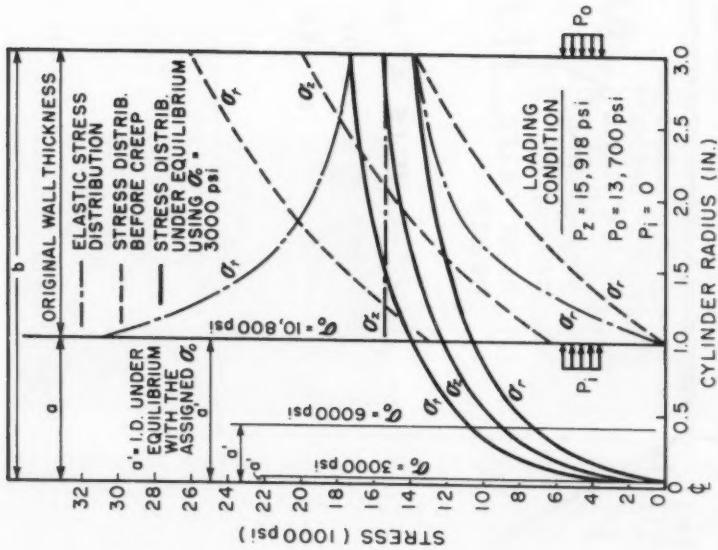


FIG. 10.—STRESS DISTRIBUTION AND REDUCTION OF RADIUS IN PROCESS OF CREEP CLOSURE OF CYLINDRICAL CAVITY.

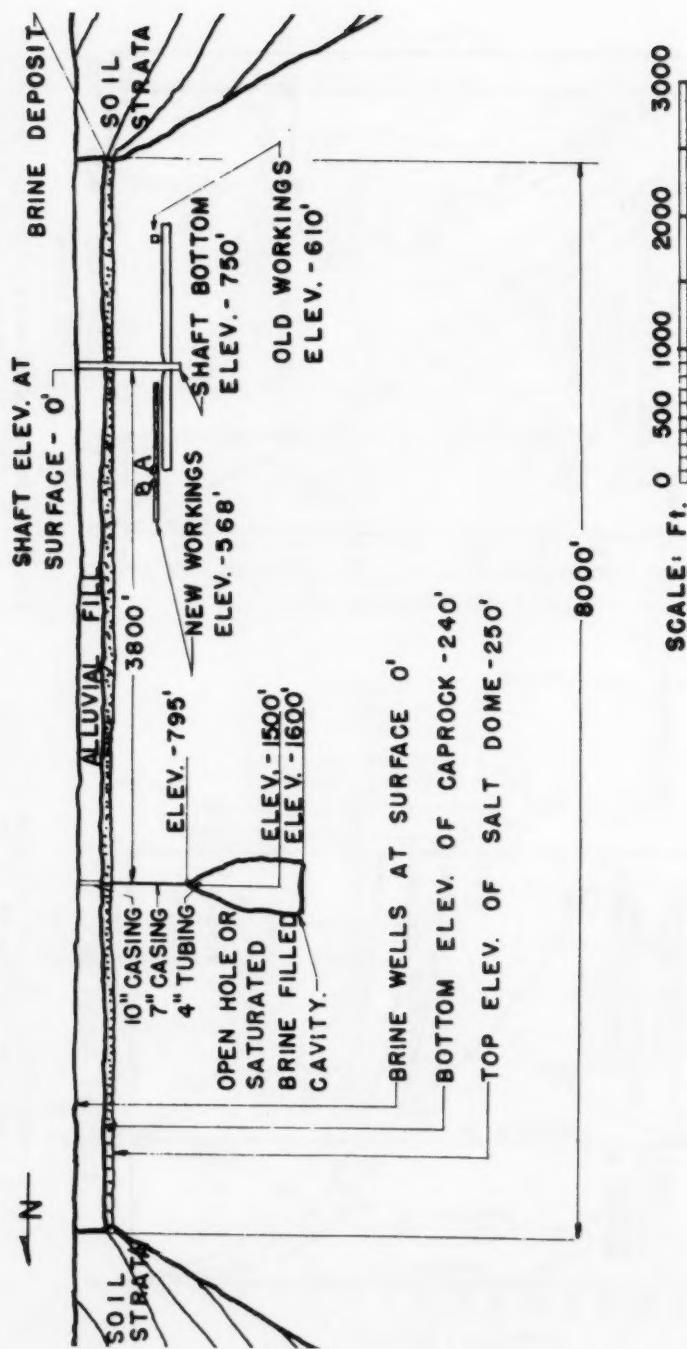


FIG. 12.—PROFILE OF GRAND SALINE SALT DOME.

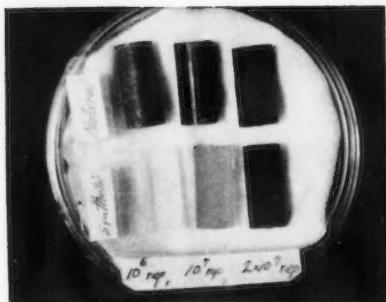


FIG. 13.—DARKENING EFFECT OF GAMMA IRRADIATION UPON NATURAL AND SYNTHETIC SALT CRYSTAL.

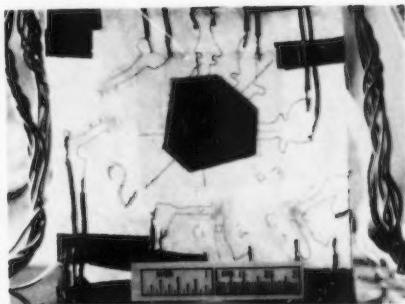


FIG. 14.—SR-4 STRAIN GAGES; TYPE AR-1 FOR STRAIN IN AGGREGATE AND TYPE A-8 FOR STRAIN IN GRAINS.

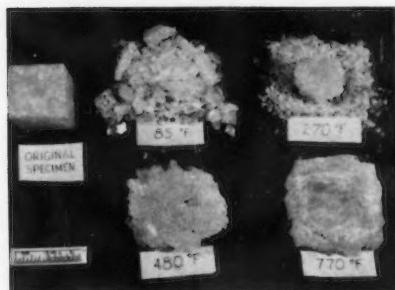


FIG. 15.—SPECIMEN TESTED BY UNIAXIAL COMPRESSION SHOWING INCREASE OF DUCTILITY WITH INCREASE OF TEMPERATURE.

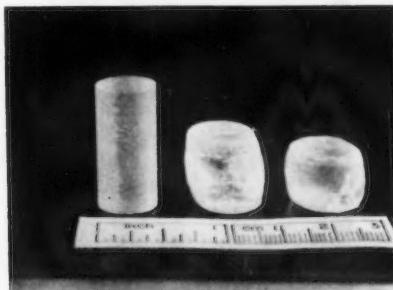


FIG. 16.—CRYSTAL FROM GRAND SALT LINE SALT MINE TESTED WITH CONFINING PRESSURE OF 14,500 psi AT 300°F AND 570°F. (LEFT, ORIGINAL; MIDDLE, 300°F, RIGHT, 570°F).

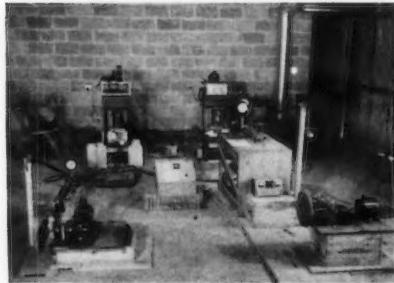


FIG. 17.—CREEP TEST AND HEATING APPARATUS.

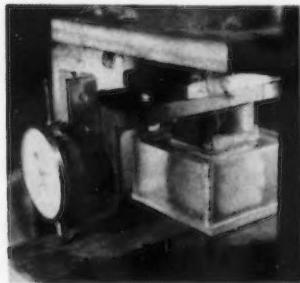


FIG. 18.—CREEP TEST OF STANDARD SPECIMEN SUBMERGED IN REACTOR FUEL WASTE SUBSTITUTE. (ALUMINUM NITRATE SOLUTION).

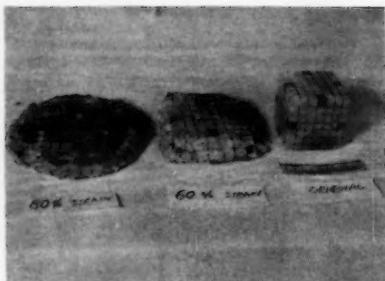


FIG. 19.—PLASTIC DEFORMATION OF SPECIMEN BY UNIAXIAL COMPRESSION AT 770°F.

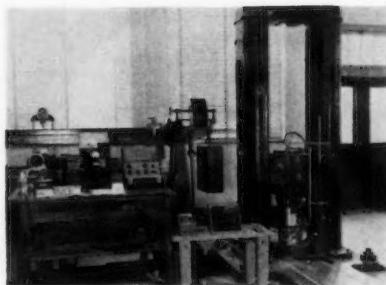


FIG. 20.—400,000 POUND TEST APPARATUS FOR MEASURING CREEP RATES IN CYLINDRICAL CAVITY.

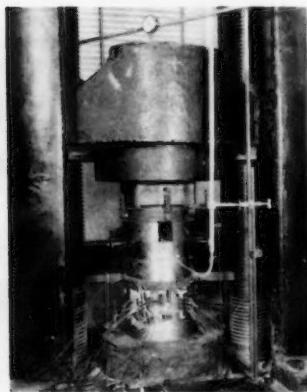


FIG. 21.—CYLINDRICAL CAVITY TEST APPARATUS

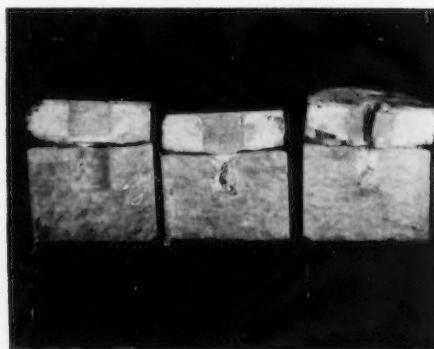


FIG. 22.—CLOSURES RESULTING FROM CREEP IN CYLINDRICAL SALT CAVITY. (6" O.D x 2" I.D)



FIG. 23.—PARTIALLY CLOSED CYLINDRICAL CAVITY.



FIG. 24.—THE 98% CAVITY CLOSURE.

Gamma irradiation of salt up to 20×10^6 rep has no effect upon the fundamental structural properties of salt. However, irradiated salt exhibits a slight reduction in the rate of transient creep. Examples of irradiated salt crystals are shown in Fig. 13.

The maximum stress of salt is not affected by its submersion for one month periods in light mineral oil, reactor fuel waste substitute (nitrate waste), and saturated salt water. Salt submerged in the saturated salt water exhibited some increase in creep, although no similar effect was found in the salt submerged in the reactor fuel waste substitute. A submerged specimen is shown in Fig. 18.

LABORATORY EXPERIMENT OF CAVITY CLOSURE

The analytical theory of cavity equilibrium was tested in the laboratory by using a model salt cavity. A cylindrical hole 2 in. inside diameter and 2 in. deep was cored out of the center of a cylindrical salt specimen of 6 in. outside diameter and 6 in. high. As seen in Fig. 9, this specimen was fitted tightly into a stainless steel cylinder. A triaxial stress condition is created around the cylindrical salt cavity simply by giving axial pressure, since the lateral pressure is produced by reaction of the steel cylinder against the lateral expansion of the salt. This lateral pressure was measured by strain gages attached to the outside of the steel cylinder, as shown in Figs. 9, 20, and 21.

About 16,000 psi of axial compressive stress was produced around the salt cavity by applying a vertical load of 400,000 lb on top of the specimen. The rate of cavity closure was determined by measuring the displacement of mercury from the cavity while the vertical load was kept constant. This loading was continued until the rate of the closure approached zero as a result of the creep equilibrium established around the cavity.

Analysis of the cavity closure and stress distribution is presented in Fig. 10. Assuming that the salt behaves as an elastic under this compression, the maximum differential stress was calculated to be 31,000 psi. Since such a large differential stress cannot exist, a stress-distribution calculation was made assuming that the salt deformed plastically. As shown in Fig. 10, the difference between the plastic stress distribution and the elastic stress distribution is noticeable.

By assuming plastic deformation, the maximum differential stress in the salt is reduced from 31,000 psi to 13,000 psi, which is obviously still much higher than salt can withstand. This excess differential stress becomes the driving force for closure of the cavity by creep. The equilibrium condition is established by reducing the cavity volume, resulting in an increase in the factor describing the plastic front ρ/a . This process of establishing a structural equilibrium is, in principle, the same as that for the development of a plastic zone. The process of the cavity closure is shown in Figs. 22, 23, and 24.

ACTUAL CREEP MEASUREMENT IN THE GRAND SALINE SALT MINE

In order to confirm the previously developed theoretical conclusion about the structural equilibrium of a salt cavity, the actual creep in the Grand Saline salt mine was measured at a depth of 700 ft. The self-explanatory pictures of the mine are shown in Figs. 25 to 30. A device, as shown in Fig. 25, equipped with a dial gage, was designed to measure the rate of closure. Two locations

in the mine, A and B, which were opened at different times (A in 1947, and B in 1952) were chosen for measurement of the closure rate, as shown in Fig. 12. By selecting these two stations, the effect of age upon the closure rate was studied. The SR-4 strain gages used for creep measurement failed because of gage corrosion. The test device is shown in Fig. 27.

As the result of measuring creep for over a year, a remarkable difference in the creep rate of the new and old opening was found, as seen in Fig. 11. This difference in the creep rate indicates a reduction of creep rate with time. From the experimental data, the following empirical formula for the creep rate is found:

$$\frac{d\epsilon}{dt} = -0.82 e^{-(t+3.0)} \dots \dots \dots (15)$$

This equation indicates that the creep in the mine will soon be extinguished.

The total amount of strain in the opening can be calculated from integration of the above creep rate equation as:

$$\epsilon = \int_{t_1}^{t_2} d\epsilon = -8.2 \int_{t_1}^{t_2} e^{-(3.0+t)} dt \dots \dots \dots (16)$$

The ultimate total strain can be obtained by taking $t_1 = 0$ and $t_2 = \infty$ as:

$$\epsilon = \int_0^{\infty} d\epsilon = 0.82 e^{-3} = -4.1\%$$

Timber beams broken by the creep are often found in the older openings of the mine as shown in Fig. 29. Measurement of the broken beams indicates that the openings have shrunk 1% to 2% over the past 15 yr to 20 yr. This agrees with the above calculation if the beams were erected there several years after the mine was opened.

The extinction of the mine creep and the nature of the empirical creep equation are positive proof of the fact that the mine opening establishes a structural equilibrium by developing plastic zones around the corners of the opening where high stress concentrations develop. All the evidence observed in the mine not only agrees with the theoretical conclusion of structural cavity equilibrium but also points favorably to stability of the cavity for waste storage use.

DESIGN PRINCIPLE

The principle for designing a salt cavity can be derived from the previously described theoretical and experimental investigations. The structural equilibrium of a salt cavity can be evaluated from these analyses, assuming that a chemical equilibrium between the salt and the waste does not become paramount.

The structural equilibrium of a salt cavity can be determined from three principal factors: the structural loading factor, cavity volume reduction, and the temperature rise in the cavity. Any one of these three factors can be determined from Fig. 7 if the other two are known.



FIG. 25.—STATION B; MEASURING CREEP CLOSURE RATE OF MINE OPENING BY USING DIAL GAGE DEVICE.



FIG. 26.—TYPICAL SUPERFICIAL SCALING WITH SHARP ANGLE OF FRACTURE DEVELOPED AT VERTICAL CORNER OF PILLAR.



FIG. 27.—POINT NO. 1; SR-4 STRAIN GAGE MEASUREMENT ON WALL OF MINE.



FIG. 28.—IMPURITY STRATA INDICATING PREVIOUS HISTORY OF DEFORMATION



FIG. 29.—BROKEN TIMER FRAMES RESULTING FROM CREEP.



FIG. 30.—MINE OPERATION AT 700 FT. BELOW SURFACE IN GRAND SALINE SALT DOME IN EAST TEXAS.

The most practical application of this method will be finding the maximum allowable temperature rise of a cavity at a given depth, when the reduction of cavity volume is limited by a particular value. For example, in a spherical cavity at depth of 1,000 ft, the maximum allowable cavity temperature rise is found to be around 500° F, with an expected cavity volume reduction of 20%.

The factor of structural loading is directly related to the allowable cavity temperature rise and the cavity volume reduction, given a structural equilibrium condition. This factor, X, is composed of three elements as previously defined.

It should be noted that the structural load on a cavity is proportional to the external and internal pressure difference, and inversely proportional to the equivalent yielding stress. Therefore, the structural load can be reduced by shortening the cavity depth or raising p_i until it approaches p_0 .

The cavity should be designed for the maximum loading condition at any given depth by assuming p_i as zero. In practice, however, the p_i value should be maintained above the vapor pressure of the waste in order to prevent boiling of the waste. The minimum internal pressure required to prevent boiling of the waste is a little less than the vapor pressure of water, which is as follows:

Temperature	The Vapor Pressure of Water
212° F	15 psi
300° F	58 psi
400° F	250 psi
500° F	681 psi
600° F	1,553 psi
700° F	3,100 psi

Increase of the internal pressure over the external pressure must not be allowed, because it will cause a cavity fracture. A cavity should be designed with excess space so that the stored waste will not be forced out when the ultimate reduction of cavity volume is reached.

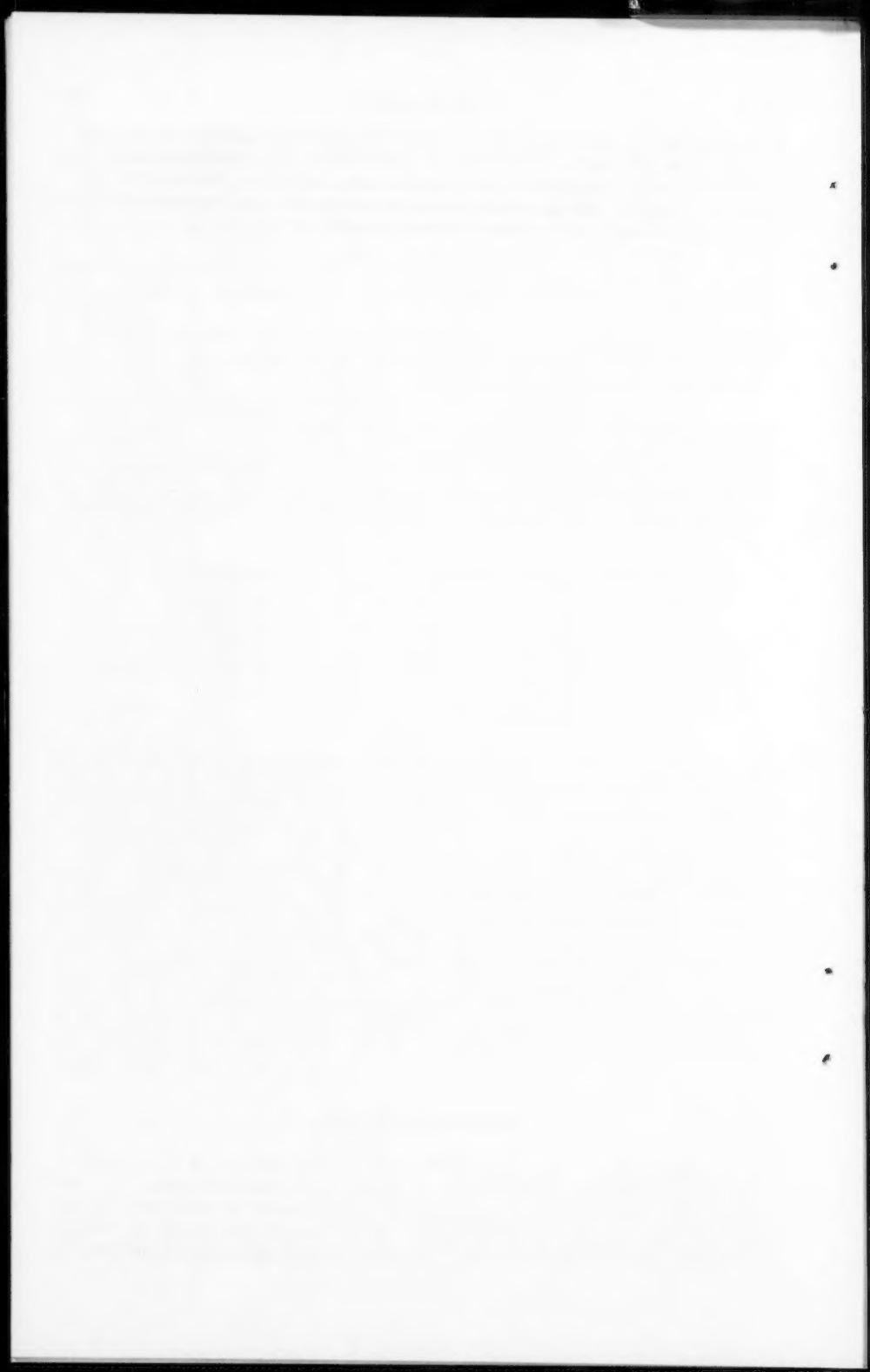
In general, when the ambient temperature of the salt formation is around 100° F, a cavity temperature rise of 400° F is permissible. The maximum allowable limit appears to be about 500° F in such a cavity. On the other hand, the cavity temperature, which is the sum of the cavity temperature rise and the ambient temperature, is limited by the vapor pressure of the waste. Therefore, the cavity temperature should be maintained below the point where the vapor pressure of the waste is equal to the overburden pressure.

There is no structural restriction upon the size of a cavity, except that the cavity radius should not exceed one-third of the overburden depth. Therefore, in most cases, the size of the cavity should be determined in relation to the cavity temperature rise.

ACKNOWLEDGMENTS

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J. Handin and M. K. Hubbert of the Shell Development Laboratory who conducted some salt tests. The writers' appreciation for assistance given by Read Lesser, superintendent of the Grand Saline plant of the Morton Salt Company, in supplying salt specimens and furnishing men and machines for experiments conducted at the mine is acknowledged.



Journal of the
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REGIONAL PLANNING IN CUYAHOGA COUNTY, OHIO

By Alfred A. Estrada,¹ F. ASCE

SYNOPSIS

The paper points out the problems created in the fields of water supply and sewerage by the post-war population boom. The manner in which the problem was studied and the observations that were made are examined.

THE PROBLEM

The rapid post-war growth, both in population and in industrial activity, of the Cleveland, Ohio, metropolitan area has brought with it many problems. Not the least among these are problems involving water supply, sewage collection and disposal, and storm-water drainage. Facilities which were adequate a few years ago are now inadequate. Sewage treatment plants are, or are becoming, overloaded and must be enlarged or rebuilt. Areas where septic tanks were formerly sufficient must now have sewers and treatment plants. Discharge of raw sewage into the streams and into Lake Erie, tolerated at one time, is now prohibited. Heavier storm water run-off, due to development of land and increasing property values, have resulted in greatly increased damages and inconveniences due to flooding. A program of construction of sanitary and storm water facilities is urgently needed.

Note.—Discussion open until October 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SA 3, May, 1960.

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Added to the need for these facilities is another problem. Whereas the population was formerly concentrated largely in the City of Cleveland, it is now spreading all over the County, beyond the city limits. The sanitation problem concerns not only the City of Cleveland, but, also, the entire County. There is no single existing governmental agency which is adequate to meet the problem. Sewerage facilities involving several municipalities must be built. In many places, flooding occurs in one area from storm water falling in another municipality. Some flood-control facilities must be built which will benefit several communities. Construction of such regional projects is retarded because of inadequate financial and administrative facilities. The need for some type of regional district with the necessary authority is, thus, indicated.

STATUS OF PROGRAM

To solve these problems, in 1948, the Regional Planning Commission began a comprehensive study of the metropolitan water and sewerage problems. Since then, a development program has been undertaken and the following steps have been carried out:

1. In 1949, the General Assembly of the State of Ohio adopted enabling legislation in the form of the "Regional Water and Sewer Act."
2. In 1950, a \$500,000 County bond issue was voted to finance a master water and sewer plan.
3. The Regional Planning Commission was authorized to undertake preparation of the plan and established a coordinating committee of engineers to supervise the project.
4. The firm of Wainwright and Ramsey of New York, N.Y., was engaged as financial consultant.
5. In 1953, a report, entitled "The Sewer and Water Problem," was prepared by the Regional Planning Commission.
6. The firm of Havens and Emerson, Consulting Engineers, of Cleveland Ohio, was engaged to prepare a master water plan, which was completed in August, 1953.
7. The Real Property Inventory, a statistical organization of Cuyahoga County, was engaged to prepare population forecasts.
8. For preparation of the master sewerage plan, the County was divided into four parts, and each part was assigned to a local engineering office, designated as an "Area Engineer." In connection with this work, the Planning Commission obtained aerial topography of the critical portions of the County. The reports of these Area Engineers were completed in 1956 and 1957.
9. The firm of Albright and Friel Inc., was engaged, in 1956, to coordinate the reports of the four Area Engineers. This work was to insure the orderly development of integrated systems for the collection and disposal of sewage and the handling of storm water within Cuyahoga County. The work was, also, to include the devising of a workable plan for financing, administration, and operation of the integrated systems. The report covering this assignment was completed on December 30, 1956, and this paper will summarize its findings.

SANITARY SEWERS

The first major function of the assignment was to review sanitary projects studied by the Area Engineers.

The Area Engineers studied some 35 sanitary sewerage projects which were estimated to have a construction cost of approximately \$104,000,000.

Twenty-eight of the projects were considered by the Area Engineers for immediate construction and these were reduced to 25 projects due to consolidations by the restudy.

It has been conceived that a central agency such as a proposed Regional District would finance the construction of only those portions of the projects which would be considered regional in scope. The costs have been separated into local sewers and the regional parts of the project defined as main intercepting sewers and sewage treatment works. Sewers included in the Area Engineers' study, which have been considered local sewers, include branch intercepting sewers and branch sewers. For the purposes of this report, main intercepting sewers were considered to be sewers which drain at least 20% of the entire drainage area. This limitation was to be waived in cases where an intercepting sewer must pass through one municipality to serve an upstream municipality. In this case, the boundary of the upstream municipality would be the limit of regional construction.

The 25 projects under consideration for immediate construction are estimated to have a total cost of \$46,347,000. These project costs would break down into Regional and Local Costs as follows:

a) Regional Construction	
Main Intercepting Sewers -----	\$17,583,000
Sewage Treatment Plants -----	<u>18,387,000</u>
Total Regional Construction -----	\$35,970,000
b) Local Construction	
Branch Intercepting Sewers -----	<u>10,377,000</u>
TOTAL -----	\$46,347,000

STORM DRAINAGE

A second major function of the assignment was to review the work of the Area Engineers who took an inventory of existing drainage systems and who designed necessary improvements. The Area Engineers studied numerous improvement projects estimated to cost a total of some \$74,000,000. These projects included many items of construction which were considered to be of a local nature. In order to differentiate between local and regional, a limit of construction was adopted for this report establishing that the Regional District would construct only the portion of projects which had a 1/2 sq mile (320 acres) or more of drainage area.

After adjusting the work studied by the Area Engineers for the regional limitation and adding nine projects which were studied individually by Albright and Friel Inc., the total program studied was condensed to 51 projects with a total estimated cost of \$42,943,000.

This total program contemplates the construction of 16 storm trunk projects, 21 single improvement projects, 7 stream enclosures, 2 projects involving general improvement and stream enclosures, 4 retarding basins, and the modification of one existing retarding basin.

May, 1960

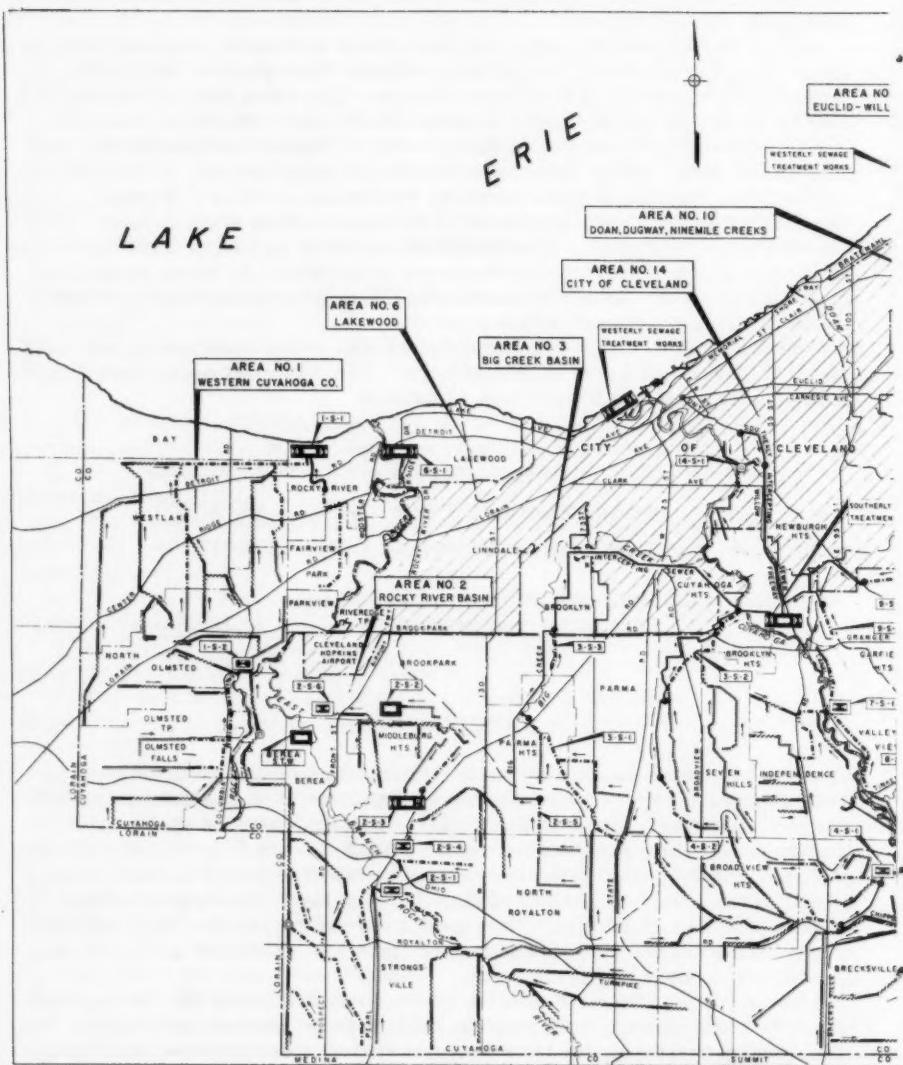


FIG. 1



FIG. 1 (CONTINUED)

Thirty-four of these projects, costing an estimated \$30,846,000, are considered ready for immediate construction.

CREATION OF A UNIFIED AGENCY

Under the terms of the resolution initially employing Albright and Friel Inc., the Engineers were requested to prepare a program for the construction, financing, and administration of the necessary physical works and structures in the program. It is concluded that to solve the problem satisfactorily, it is necessary that there be created, or expanded in power, a political subdivision having jurisdiction for all of Cuyahoga County. This entity would be either a regional water and sewer district as permitted under the statutes of the State of Ohio, a County form of government organized under a charter containing powers at least equivalent to that granted to regional water and sewer districts, or some other governmental agency of equivalent powers.

Throughout this paper reference will be made to a Regional District primarily for convenience; it is contemplated that such terms include a county with a charter granting adequate powers or some other sufficiently empowered subdivision.

PAYMENT FOR TRANSFER OF EXISTING FACILITIES

Any successful program must contemplate that the District would acquire all sewage treatment works, together with their main intercepting sewers. In such acquisition, it is contemplated that the District would acquire such facilities by an agreement to pay the outstanding remaining debt on such sewage treatment works and main intercepting sewers. It would acquire all of the other existing facilities. Since they would not be of a regional character, under the definition established, they should be acquired without cost to the District. The remaining debt on these facilities is nothing more than an assessment of the remaining benefits for the local area served.

However, in the case of the City of Cleveland, two alternatives are suggested. Under the plan for the payment of outstanding debt, the District would pay the yearly debt service charges of the City of Cleveland, for sewage treatment works and main intercepting sewers, which would be about an average of \$561,500 a year for the next 22 yr.

An alternative to this method of settlement has been developed. The City, at the present time (1960), collects a sewer rental of 25¢ per 1,000 cu ft from city residents, and 46¢ per 1,000 cu ft from suburban sewer users. This differential was developed by an Advisory Board to the City in 1939, and represents the City user's share of fixed charges which are and have been paid for out of ad valorem taxes. Under the alternative, the District would pay the City of Cleveland a yearly sum equal to the product of the amount of water billed for sewage charges within the City of Cleveland, multiplied by the differential in rate between the city users and suburban users. If this premise is carried out, there would be a yearly payment of \$1,333,500.

For the purposes of an exploratory study of a required rate structure, the yearly sum of \$1,333,500 has been used as an obligation of the proposed District to the City of Cleveland which would be carried over 22 yr.

Variations on the discharging of this obligation would be: (1) A direct yearly payment to the City, (2) a preferred sewer rental rate to the City of Cleveland users, (3) a combination of both.

It is contemplated that the proposed Unified Agency would take over and maintain all storm sewers, drainage ditches, and drainage structures which would have 1/2 sq mile or more of drainage area. These existing facilities would be taken over at no cost to the Agency.

DIVISION OF COST RESPONSIBILITIES ON NEW CONSTRUCTION

In regard to the cost responsibilities of new construction, the recommendations can be summarized as follows:

(a) That in sanitary sewer systems, branch sewers, and branch intercepting sewers would be constructed by the local municipality which could be financed by funds raised by ad valorem taxes or an assessment on a front foot and/or area basis.

(b) That main sanitary interceptor sewers would be constructed by the Unified Agency with funds raised to the extent of 90% of the cost by an assessment against the area served, and the other 10% would be paid through sewer rentals. The assessment bonds should mature over a 20-yr period and the assessment to properties benefited could be paid in twenty yearly installments. Any relief sewers constructed to supplement an existing main intercepting sewer would be financed entirely through sewer rentals.

(c) That sewage treatment plants would be financed by the Unified Agency with the issuance of bonds supported by sewer revenues, which bonds would mature over a 40-yr period at maturities established so that the yearly amortization cost of principal and interest would be approximately equal.

(d) That storm sewer projects, limited to projects with not less than 1/2 sq mile drainage area, would be financed and constructed by the Unified Agency which would be supported by ad valorem taxes paid by the entire country. Drainage structures on areas less than 1/2 sq mile in drainage area would be constructed by the local municipality.

ASSESSMENT AND REVENUE REQUIREMENT STUDIES-SANITARY PROJECTS

Assessment and revenue requirement studies have been made which entailed the preliminary assembly of factual data on tributary areas to proposed main intercepting sewers, population now served and to be served by the sewer system, operating and maintenance cost of existing treatment plants and sewers, together with an estimation of costs that would be involved in the administration and engineering force required for a Unified Agency.

Intercepting Sewer Assessment Charges.—In the development of assessment studies, as previously stated, it was contemplated that main intercepting sewers would be assessed against the properties benefited on an acreage basis. The results of these exploratory studies indicate that for the seventeen projects involving main intercepting sewers now under consideration, the assessment costs per net acre would range from a low of \$35 per acre to a high of \$1,095 per acre, with a median of \$320 per acre. The assessment per house, using 2.4 houses per acre would range from a high of \$460 a house to a low of \$15 a house, with a median of \$134 a house. These assessments

could be paid by the property owners in twenty equal annual installments and would have the following range:

	Yearly Assessment Charge
High - - - - -	\$32 per yr
Median - - - - -	9 per yr
Low - - - - -	1 per yr

Sewer Rental Charges.—Sewer rentals must recover sufficient revenues to pay for a small portion of the amortization cost of intercepting sewers, the amortization cost of treatment plants, payments for existing facilities, operation and maintenance costs of sewers and sewage treatment works. Projected sewer revenues have been developed under two alternate plans as follows:

Plan No. 1 - A District embracing all of Cuyahoga County, including the City of Cleveland.

Plan No. 2 - A District embracing all of Cuyahoga County, excluding the City of Cleveland.

Plan No. 1 has been further subdivided as follows:

A) Based on a yearly payment for existing facilities to the City of Cleveland, without a preferential sewer rental rate.

B) Based on a yearly payment to the City of Cleveland, with a partial preferential sewer rental rate.

C) Based on no payment to the City of Cleveland, with a full preferential sewer rental rate.

A tabulation of the sewer rentals under the subdivisions in Plan No. 1 are summarized as follows:

	<u>"A"</u>	<u>"B"</u>	<u>"C"</u>
Yearly Payment to City of Cleveland	\$1,333,500	\$776,250	0
Rate to Cleveland Users Per 1,000 Cu Ft Per Equivalent Connection (15,000 Cu Ft/Yr)	\$0.69	\$0.60	\$0.48
Rate to Others in Cuyahoga County Per 1,000 Cu Ft Per Equivalent Connection	\$10.35	\$9.00	\$7.20

Under Plan No. 2, exploratory sewer rental charges to all participants in the Unified Agency have been developed based on two subdivisions. These subdivisions are on the basis of the present charge for sewage treatment by the City of Cleveland, of 46¢ per 1,000 cu ft and a possible future charge by the City to show the reflection of an increase which, for purposes of preliminary discussion, has been shown as 52¢ per 1,000 cu ft. The estimated sewer

rentals to all participants of the District, together with the estimated yearly charge to be paid to the City for sewage treatment, are summarized as follows:

Subdivision	Rate Charged for Sewage Treatment by Cleveland Per 1,000 Cu Ft	Yearly Payment to Cleveland	Charge to Users	
			Per 1,000 Cu Ft	Per Equivalent Connection Per Year
A	\$0.46	\$657,400.00	\$1.15	\$17.20
B	\$0.52	\$743,100.00	\$1.19	\$17.70

STORM SEWER CHARGES

The amount of general obligation bonds required to defray the cost of immediate storm sewer improvements would be \$30,846,000. Based on a 20-yr issue of general obligation bonds bearing interest at 3-1/2%, and based on assessed valuation of \$4,700,748,044 in the county, the yearly debt service requirements and the tax increase would be as follows:

	Yearly Debt Service Requirement	Estimated Tax Increase	
		Per \$100 Assessed Value	For House With \$10,000 Assessed Value
First Year	\$2,536,000	\$0.0537	\$5.37
Average for 20 Yr	\$2,050,000	\$0.0426	\$4.26

ADVANTAGES AND DISADVANTAGES OF THE UNIFIED PLAN

Morris M. Cohn in an article in the October, 1957 issue of "Wastes Engineering," stated:

"The era of metropolitan growth which is spreading like wildfire from coast to coast poses a great challenge to the sewage and industrial wastes field."—and went on further to say: "This is the time for a cosmopolitan approach to a cosmopolitan problem. The parent city cannot turn a deaf ear to the needs of suburban areas which surround the city boundaries, nor can the fringe areas use the attitude of a child which leaves the family circle and expects and demands support from its parents. There is an integration of interests which should serve as an amalgamating force to fuse the municipality and its ring areas into a stronger and more useful governmental alloy. There exists a two-way challenge to the parent community and to the fringe area, if common utility services could be of common good to both."

This article illustrates the fact that the sewage and drainage problems in the Cleveland-Cuyahoga County Area are similar to the problems faced by other areas throughout the country, and, also, illustrates the spirit of co-operation that has existed in Cuyahoga County in the past and that must continue in the future if common problems are to be solved.

The formation of a Unified Agency to acquire, construct, and maintain the Sanitary Sewer Systems and Storm Sewer Systems in Cuyahoga County, to-

gether with a central administrative control of operation of the sewage plants, would answer this two-way challenge in the Cleveland-Cuyahoga County Area, and would have the following advantages:

1. The water supply of the region which is primarily represented by the City of Cleveland Water System would be protected from the ever increasing discharge of overflowing cesspools and inadequately treated sewage.
2. The rivers and streams in the area would be preserved for recreational use.
3. The enlarged agency would be in a position to provide treatment facilities and intercepting sewers on a drainage area basis which is the logical method of division instead of the division by political boundaries.
4. A Unified Agency, with appropriate powers, could facilitate and, in some cases, make possible the financing of necessary sewers and sewage treatment works which might be impossible to finance by the individual municipalities with today's high construction cost and high interest cost on bond issues. While at the present time some municipalities are being assisted by the County through financing under County backed bonds, this assistance cannot cover all projects which now require attention.
5. The solving of drainage problems on a drainage area basis, in lieu of a political boundary basis will allow for an orderly development of necessary drainage facilities and the protection of properties along the streams and rivers.
6. The engineering staff of the District would be in a position to make exploration studies and preliminary designs for storm sewers and sanitary sewers in needy areas, anticipating necessary improvements.

The disadvantage of the Unified Plan would be the increased cost which the residents of the City of Cleveland would have to pay for sewage treatment. This increase in cost can be established by the difference between (1) the actual cost for sewage treatment when the City of Cleveland plants would be expanded and (2) rental cost to the City residents under Plan One. The charge to residents and non-residents of the City of Cleveland would be approximately 52¢ per 1,000 cu ft or \$7.80 a yr per 15,000 cu ft. This would compare with a charge under Plan No. 1 of \$10.35 per 15,000 cu ft, or a difference of \$2.55 per yr per average domestic connection. The sewage treatment charge, as determined herein for the average domestic connection discharging 15,000 cu ft per yr, can be compared with the charges made for a like quantity of sewage in cities of 100,000 population or larger as shown in Table 1. The proposed rate in Cleveland is less than in any of these cities except Dayton.

This report cannot be expected to produce a fixed formula which will instantaneously be acceptable to officials of all municipalities concerned. The report, however, does expose the various facets of the problem so that men and women with a common purpose can intelligently negotiate agreements which will solve this difficult problem.

TABLE 1.—ANNUAL SEWER RENTAL CHARGES IN CITIES OF OVER
100,000 POPULATION FOR DOMESTIC SEWER USERS DISCHARGING
15,000 CU FT OR 112,200 GAL OF WASTE PER YR

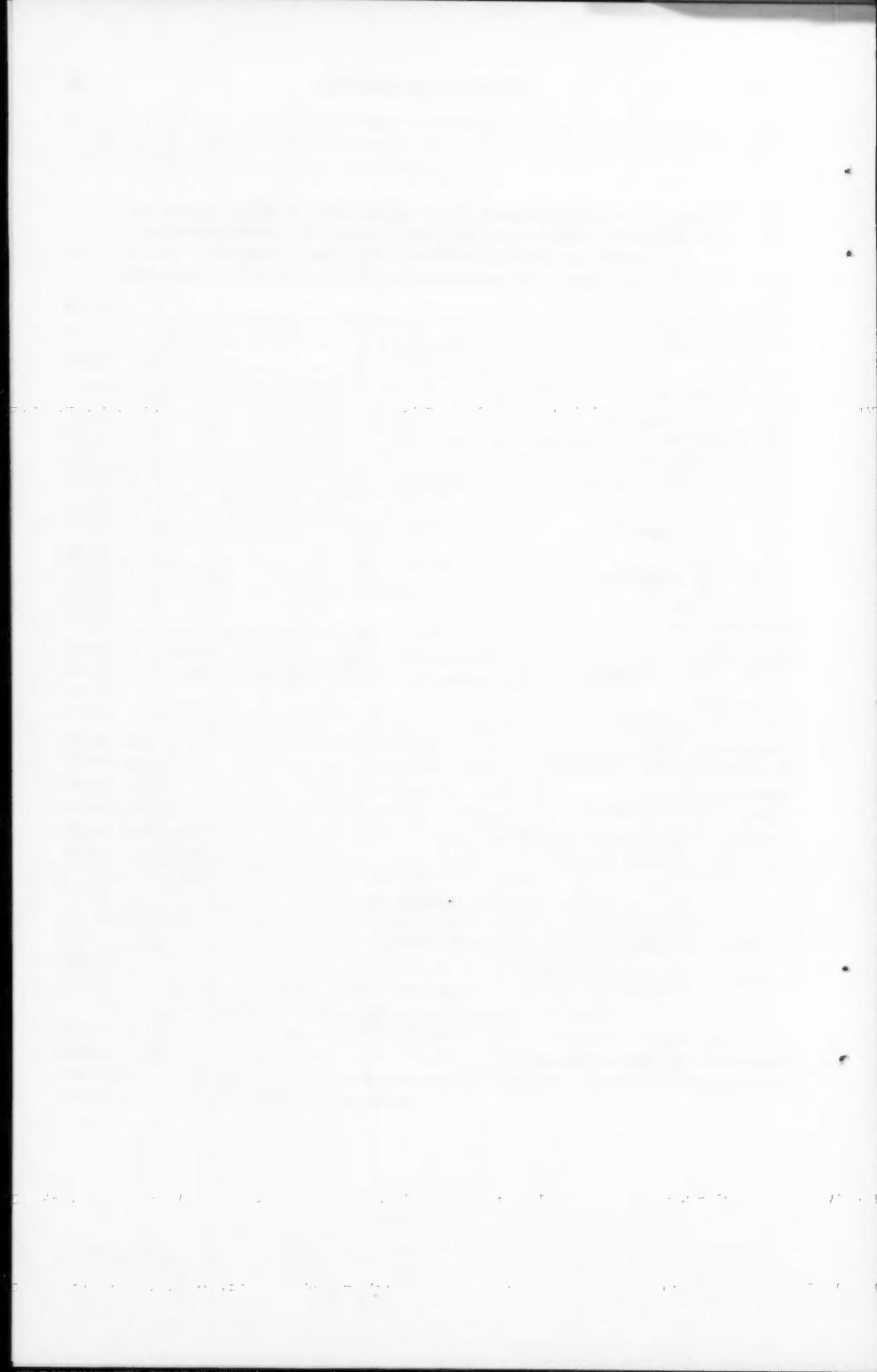
Philadelphia, Pa.	\$27.66
Little Rock, Ark.	27.72
Camden, N.J.	33.68
Jersey City, N.J.	32.30
Chattanooga, Tenn.	14.04
Chattanooga, Tenn. - Suburban	21.36
Knoxville, Tenn.	22.20
Knoxville, Tenn. - Suburban	33.60
Akron, Ohio	16.50
Akron, Ohio - Suburban	18.15
Canton, Ohio	12.60
Canton, Ohio - Suburban	19.70
Columbus, Ohio	20.25
Columbus, Ohio - Suburban	33.75
Dayton, Ohio	8.40
Dayton, Ohio - Suburban	10.50
Toledo, Ohio	12.90
Toledo, Ohio - Suburban	18.15
Youngstown, Ohio	41.70
Youngstown, Ohio - Suburban	52.80
Cincinnati, Ohio	12.00
Cincinnati, Ohio - Suburban	12.00
Cleveland - Present with Tax Subsidy	3.75
Cleveland - Suburban Present	6.90

Proposed Under Plan 1

Cleveland - Proposed with Tax Subsidy as at present with no Subsidy	7.20 10.35
Cleveland - Suburban - Proposed	10.35

Proposed Under Plan 2

Cleveland - Suburban - Proposed	17.70
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Journal of the
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OXYGEN BALANCE OF AN ESTUARY

By Donald J. O'Connor,¹ M. ASCE

SYNOPSIS

The net seaward movement of organic impurities in estuaries is due to the displacement by the land runoff and to the longitudinal diffusion of the tidal action. The dissolved-oxygen profile depends on the concentration of the organic material, its rate of oxidation, and the resulting rate of reaeration. The interrelationship among these geophysical and biochemical factors is described by a differential equation under a steady-state condition. The assumption of constant coefficients in the equation is confirmed by the field data from estuarine surveys of the Delaware and the James Rivers. Dissolved-oxygen profiles are calculated from the integrated equation and compared to the measured dissolved-oxygen concentrations. The turbulent diffusion coefficient and the deoxygenation rate are determined from an analysis of survey data and are used in the calculation of the oxygen profiles. The agreement between the calculated profiles and the observed values is sufficiently close to justify the use of the equations for the conditions assumed in the development.

INTRODUCTION

The forces of natural self-purification can bring about the return of polluted waters, in time, to a condition of acceptable cleanliness and ultimately to one of natural purity. The time factor is of paramount importance in this process. In a flowing stream, the predominant motion is due to gravity and the formu-

Note.—Discussion open until October 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SA 3, May, 1960.

¹ Assoc. Prof. of Civ. Engrg., Manhattan College, N. Y., N. Y.

lations describing this motion are sufficiently accurate to permit calculation of the time of travel. If more accurate determinations are required, reliable and simple methods of measuring velocities in the field are available. The time of travel is markedly changed, however, in those sections of the river which are subjected to tides. The motion of these waters is caused not only by gravity but also by tidal action, density currents, and wind effects. Waste materials which are discharged into estuaries are mixed with the water and are gradually diminished in concentration by the tidal motion, which carries various portions of the pollutant back and forth over many cycles. Any slug of pollutant is ultimately translated to the open sea and this time is referred to as the flushing time rather than the travel time. The flushing time is the resultant of the translating velocity of the river flow and the longitudinal mixing of the tidal action. This concept is of fundamental importance in defining pollution and self-purification of tidal waters. It is the purpose of this work to present a theoretical development defining the processes which determine the distribution of dissolved oxygen in a non-stratified estuary.

REVIEW OF PREVIOUS WORK

In the past ten years (as of 1960), there has been a considerable increase in the study of estuarine mixing and flushing by oceanographers. Although the state of knowledge of these phenomena is far from complete, it has progressed to the point where many useful concepts are presently available to the engineer. An excellent review of estuarine hydrography has been presented by D. W. Pritchard.² Estuaries were defined and classified in terms of fresh-water inflow and evaporation, geomorphological structure, and circulation pattern. Pritchard defined an estuary as being "a semi-enclosed coastal body of water having a free connection with the open sea and containing a measurable quantity of sea salt."

Some of the earliest engineering studies of the flushing of pollutants from estuaries have employed the concept of the tidal prism.³ The assumption was made that complete mixing of the flood waters and polluted harbor waters occurred. This approach was improved by J. Tully⁴ and R. G. Tyler⁵ who took into account the portions of pollutant remaining after each tidal cycle. B. H. Ketchum further developed⁶ these concepts by dividing the estuary into segments, defined by an effective mixing length which is equal to the mean distance covered by the flood tide. Within each segment, mixing is assumed to be complete at high tide and the proportion of water removed and its associated pollution on the ebb tide is determined by the ratio of the intertidal and high tide volumes of the segment. Ketchum stated that incomplete vertical mixing can be taken into account in this hypothesis. A. B. Arons and H. Stommel presented⁷ a more mathematical approach, based on a mixing length theory which

² "Estuarine Hydrography," by D. W. Pritchard, Advances in Geophysics, Academic Press, New York, 1952.

³ "Pollution of New York Harbor," by E. B. Phelps and C. J. Velz, Sewage Works Journal, Vol. 5, January, 1933.

⁴ "Oceanography and Prediction of Pulpmill Pollution in Alberni Inlet," by J. Tully, Bulletin No. 83, Fish Reserve Bd., Canada, 1949.

⁵ "Disposal of Sewage into Tidal Waters," by R. G. Tyler, Sewage and Industrial Wastes Journal, Vol. 22, May, 1950.

⁶ "The Flushing of Tidal Estuaries," by B. H. Ketchum, Sewage and Industrial Wastes Journal, Vol. 23, February, 1951.

⁷ "A Mixing-Length Theory of Tidal Flushing," by A. B. Arons and H. Stommel, Transactions, Amer. Geophysical Union, Vol. 32, 1951, p. 419.

included considerations of continuity and turbulent diffusion. Stommel in a later work⁸ discussed objections to making a priori supposition about the turbulent mixing process. He suggested using the distribution of salinity and river water in order to determine coefficients of turbulent diffusion and to apply these coefficients in analysis of the dilution and distribution of pollutants. Pritchard in a study of the flushing of the Delaware model presented⁹ a similar equation for the time rate of change of mean concentration of a conservative substance. This equation was applied to the analysis of the distribution of dye which was injected at various points along the estuarine model. R. E. Kent,¹⁰ following the work of Stommel and Pritchard, evaluated the turbulent diffusion coefficients and successfully applied these to the dye distribution of the model data.

The processes of self-purification are similar in tidal waters as in river waters, but certain modifications are necessary to take into account the effect of the high salt concentrations. The progress of the biochemical oxygen demand is retarded when the concentrations of the sea water is greater than 25%. The stage of nitrification is also retarded.¹¹ The reduced rate of the BOD reaction may also be attributed to the fact that the flushing phenomenon permits portions of organic pollutants to remain within the estuary for extensive periods of time. Thus, a sample of an organic pollutant is made up of portions of various ages, some of which are probably in the nitrification stage. Variation in the most probable number of coliform organisms with tidal cycles has been observed¹² and A. N. Diachishin has defined this variation mathematically with some success for the New York Harbor samples.¹³ It is probable that other characteristics are also subjected to this variation. The saturation of dissolved oxygen is less in sea water than in distilled water. The most recent study in this regard is that of G. A. Truesdale, A. L. Downing and G. F. Lowden.¹⁴ Values of the reaeration coefficient are also reduced because of the effect of chloride concentration of the diffusivity of oxygen. The influence is partially offset by virtue of the slight increase in surface tension due to the presence of the inorganic salts. The basic relationships defining the processes of deoxygenation and reaeration in rivers must be related to the flushing times in order to define the oxygen balance in an estuary.

THEORETICAL DEVELOPMENT

An estuary is defined as being a semi-enclosed coastal body of water which is subject to tidal action and in which the sea water, if present, is measurably diluted by river flow. In terms of the geomorphological structure, this study considers the coastal plain estuaries, which characterizes most of the eastern shore of North America. This type has been formed by the drowning of former

⁸ "Computation of Pollution in a Vertically Mixed Estuary," by H. Stommel, Sewage and Industrial Wastes Journal, Vol. 25, September, 1953.

⁹ "A Study of Flushing in the Delaware Model," by D. W. Pritchard, Tech. Report VII, The Chesapeake Bay Inst., Johns Hopkins Univ., April, 1954.

¹⁰ "Turbulent Diffusion in a Sectionally Homogenous Estuary," by R. E. Kent, Tech. Report XVI, The Chesapeake Bay Inst., Johns Hopkins Univ., April, 1958.

¹¹ "Effect of Temperature on Biochemical Oxidation of Sewage," by H. B. Gotaas, Vol. XX, May, 1948.

¹² "Sampling for Effective Evaluation of Stream Pollution," by C. J. Velz, Sewage and Industrial Wastes Journal, Vol. 22, May, 1950.

¹³ "The Analysis of Water Samples for Cyclical Variations," by A. N. Diachishin, Transactions, ASCE, Vol. 122, 1957.

¹⁴ "The Solubility of Oxygen in Pure Water and Sea Water," by G. A. Truesdale, A. L. Downing and G. F. Lowden, Journal of Applied Chemistry, Vol. 5, 1955, p. 502.

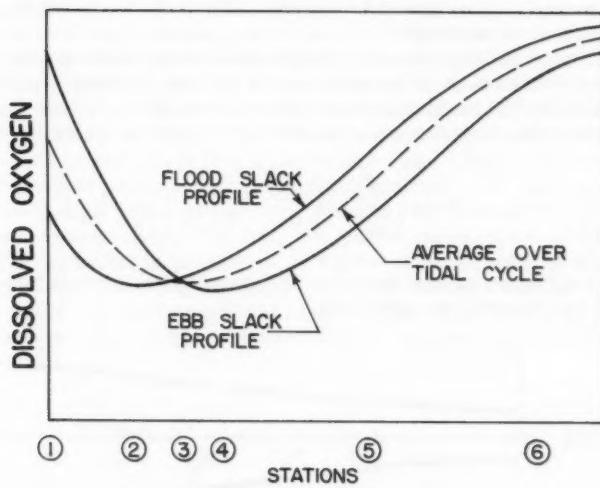
river valleys, either from subsidence of the land or from a rise in the sea level. Furthermore, non-stratification in both the vertical and lateral directions is assumed to exist.

Consider an estuary receiving no other waste matter along its course except that contributed by the land runoff from an upstream discharge. A steady state condition is assumed to exist which implies that the land runoff and the waste discharge have remained constant for a period equivalent to the time of passage through the estuary. The deaeration caused by the organic matter and the resulting reaeration produce a pattern in the dissolved oxygen concentration similar to the "sag curve" evidenced in upland rivers. Dissolved-oxygen profiles are shown in Fig. 1 indicating the average condition and those at the flood and ebb slacks. The latter two curves delineate the limits between which the dissolved-oxygen profiles move over the tidal cycle. The longitudinal displacement between these limits depends on the tidal velocity and period and the turbulence due to tidal motion. The displacement is a maximum for large values of tidal velocity and period and relatively low order turbulence. Conversely, intensely mixed tidal bodies of relatively low velocity and short period are characterized by a minimum displacement of the profiles. The cyclical variation of dissolved oxygen in time is readily defined from these profiles. The dissolved oxygen varies from a low to a high value over the tidal cycle as shown in Fig. 1. In regions where the longitudinal concentration gradient is great, there is a great variation in the dissolved oxygen over the cycle, as at stations 1 and 5. Where the concentration gradient is zero or approaches zero, the variation over the cycle is low, as at stations 3 and 6. Where the concentration gradient is negative, the dissolved oxygen varies inversely as stage height, as at station 1 and where positive, as at station 5, the variation is direct. Inspection of Fig. 1 indicates that the dissolved-oxygen concentration remains substantially constant in time at the flood and ebb slack periods. The profiles therefore can be more readily defined and more accurately measured at these periods than any other. Consider the estuary shown in Fig. 2 and described by the characteristics enumerated above. The x-axis is that of the longitudinal axis of the channel, increasing in the seaward direction. The vertical and lateral axes are designated "y" and "z." The steady state is most suitably defined by either that of the ebb or flood slack, but, from the practical viewpoint, it may also be defined by the average value over the tidal cycle.

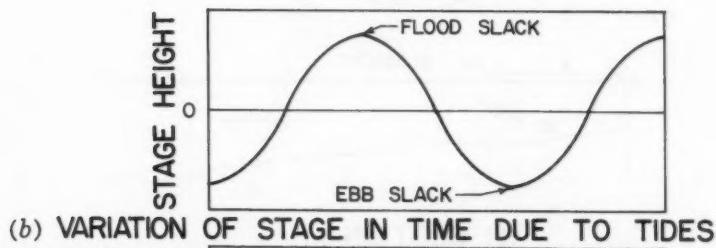
The total amount of oxygen carried into the element as shown in Fig. 2 is that contributed by (a) the flowing stream across the plane 1, (b) turbulent transport across the plane 1, and (c) turbulent transport across the plane 2.

The total amount of oxygen carried out of the element is affected by the same factors through the planes 3 and 4, plus that removed by the oxidation of the organic matter. The concentration gradients at each plane of the element in both the x and y are also shown in Fig. 2. Utilizing the concentrations and the associated gradients in a material balance in and out of the element leads to the partial differential equation which defines the oxygen distribution under a steady state:

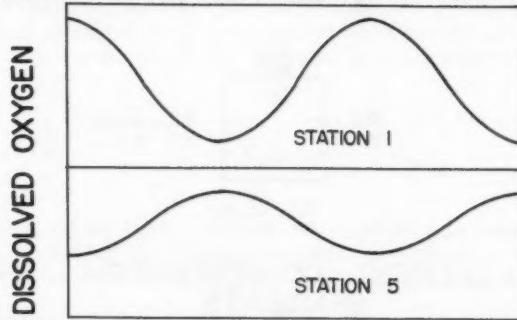
in which ϵ_x and ϵ_y are the turbulent transport coefficients in the x and y direc-



(a) VARIATIONS OF DO IN DISTANCE UNDER STEADY STATE



(b) VARIATION OF STAGE IN TIME DUE TO TIDES



(c) VARIATION OF DO IN TIME DUE TO TIDES

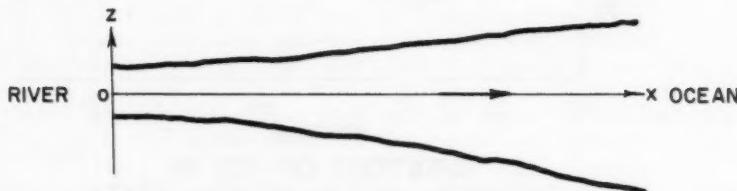
FIG. 1.—DO VARIATION DUE TO TIDES

tions, c is the concentration of oxygen, L denotes the ultimate biochemical oxygen demand, U is the forward velocity of the river flow, and K_d represents the coefficient of deoxygenation.

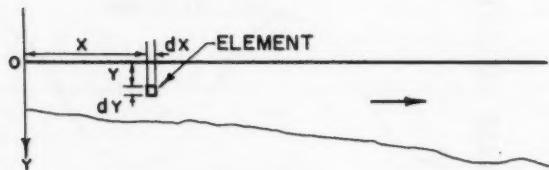
In a non-stratified estuary, the gradient in the vertical plane is essentially zero and the amount of oxygen carried into the element has been shown to be controlled by that passing through the water surface.¹⁵ This condition reduces the partial differential to an ordinary differential as follows:

$$0 = \epsilon_x \frac{d^2 c}{dx^2} - U \frac{dc}{dx} + K_2 [c_s - c] - K_d L \dots \dots \dots \quad (2)$$

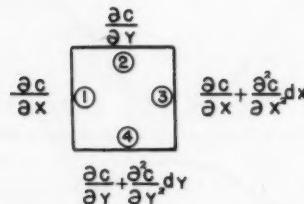
in which c_s is the saturation value of oxygen at the given temperature, and K_2 denotes the reaeration coefficient.



(a) PLAN



(b) SECTION



(c) ELEMENT CONCENTRATION GRADIENTS

FIG. 2.—ESTUARINE CONCENTRATION GRADIENTS

¹⁵ "Mechanism of Reaeration in Natural Streams," by D. J. O'Connor and W. E. Dobbins, Transactions, ASCE, Vol. 123, 1958.

In Eq. 2 the first term represents the rate of turbulent flux, produced by the tidal action, the second term is that due to the river discharge, and the third and fourth terms are, respectively, the reaeration and deoxygenation rates. The form of Eq. 2 is based on a constant value of the eddy diffusivity and a uniform channel cross section. In any actual case, neither of these conditions hold, but average values may be used if the variations from the actual are within certain statistical limits. The magnitude of the error introduced by these approximations may be evaluated in any particular case. Furthermore, Eq. 2 is developed on the basis of an increasing oxygen gradient with distance; that is, that portion of the sag curve downstream from the location of the minimum dissolved oxygen concentration. The final solution of the equation is the same if the differential equation is presented in terms of a decreasing dissolved gradient which is upstream from the minimum point. Before Eq. 2 can be integrated the variable L must be replaced as a function of x . This may be done by a similar material balance as performed for the oxygen concentration and leads to

Imposing the boundary condition that $L = L_0$ at $x = 0$ and $L = 0$ at $x = \infty$ Eq. 3 is solved as

in which

$$j_1 = \frac{U}{2\epsilon} \left[1 - \sqrt{1 + \frac{4 K_d \epsilon}{U^2}} \right]. \dots \dots \dots \quad (5)$$

Eq. 4 is similar to that developed¹⁶ by H. R. Thomas, Jr. and R. S. Archibald to define longitudinal mixing through conduits, streams and tanks.

Substitution of Eq. 4 into Eq. 2 for the value of L and rearranging terms there results

$$\epsilon \frac{d^2 c}{dx^2} - U \frac{dc}{dx} - K_2 c = K_d L_0 e^{j_1 x} - K_2 c_s \dots \dots \dots (6)$$

Eq. 6 is a second-order linear differential equation with constant coefficients and may be integrated by standard procedures. Subject to the boundary conditions that $c = c_0$ at $x = 0$ and $c = c_s$ at $x = \infty$, this equation leads to:

$$c = c_0 e^{\frac{j_2 x}{2}} + c_s \left[1 - e^{\frac{j_2 x}{2}} \right] - F L_0 \left[\frac{e^{\frac{j_1 x}{2}} - e^{\frac{j_2 x}{2}}}{e^{\frac{j_1 x}{2}} + e^{\frac{j_2 x}{2}}} \right] \dots \dots \dots (7)$$

¹⁶ "Longitudinal Mixing Measured by Radioactive Tracers," by H. A. Thomas, Jr. and R. S. Archibald, Transactions, ASCE, Vol. 117, 1952.

Eq. 7 may be expressed in terms of the dissolved-oxygen deficit as follows:

$$D = F L_0 \left[e^{j_1 x} - e^{j_2 x} \right] + D_0 e^{j_2 x} \dots \dots \dots (8)$$

in which

$$F = \frac{K_d}{K_2 + U_{j_1} - \epsilon j_1^2} = \frac{K_d}{K_2 - K_d} \dots \dots \dots (9)$$

and

$$j_2 = \frac{U}{2\epsilon} \left[1 - \sqrt{1 + \frac{4 K_d \epsilon}{U^2}} \right] \dots \dots \dots (10)$$

The similarity between Eq. 8 and that developed¹⁷ by H. W. Streeter and E. B. Phelps for rivers is evident. A unique condition can result in the following equality:

$$K = \frac{2 U^2}{\epsilon} \dots \dots \dots \quad (11)$$

In this case Eq. 5 reduces to

or

This condition, in turn, reduces Eq. 4 to one very comparable to that characteristic of upland rivers.

If the land runoff is very low or the cross-sectional areas large, which result in insignificant values of velocity, then Eq. 8 becomes

$$D = \frac{K_d L_0}{K_2 - K_d} \begin{bmatrix} -x\left(\frac{K_d}{\epsilon}\right)^{1/2} & -x\left(\frac{K_2}{\epsilon}\right)^{1/2} \\ e & -e \end{bmatrix} + D_0 e \quad \dots (13)$$

Before Eqs. 8 or 13 can be used in a practical case, the velocity term, the eddy diffusivity and the coefficients of reaeration and deaeration must be assigned numerical values.

¹⁷ "A Study of the Pollution and Natural Purification of the Ohio River," by H. W. Streeter and E. B. Phelps, Public Health Bulletin 146, USPHS, Washington, D. C. 1925.

For those cases, in which the coefficients of reaeration and deaeration are of the same order and the initial deficit is very low, then the sag equation of Streeter and Phelps may be used as an approximation for estuaries. This approximation is valid because the term in parenthesis in Eqs. 8 or 13 is a difference of exponential terms. Consequently, if the exponents are taken as $K_d t$ and $K_2 t$, as in the original sag equation, then the deficit is approximately equal to that obtained by using the exponents indicated for Eqs. 8 or 13. When the initial dissolved oxygen deficit and the difference between the coefficients of reaeration and deaeration are significant, then Eqs. 8 or 13 must be used.

EVALUATION OF THE COEFFICIENTS

The turbulent transport coefficient may be determined from a knowledge of the concentration distribution of any property in the estuary. The chloride concentration or the salinity is taken as the required steady state property. The source of this property is the coastal waters of the ocean. The turbulent flux, caused by the tidal action, diffuses salt waters into the mouth of the river. The distribution and extent of this characteristic reflects the magnitude of the eddy transport coefficient. The steady state condition predicates fresh water from one major source, with none added by ground water and removed by evaporation. The material balance of this property may be constructed in a fashion similar to that of the oxygen-demand material, which leads to

In Eq. 14, s refers to the concentration of salinity or chlorinity and the remaining terms have been previously defined. Since this is a conservative property, no decay term is included. The eddy diffusivity and the velocity are assumed to remain constant over the length of the estuary considered. Both Stommel⁸ and Kent¹⁰ more correctly assumed these parameters to vary with distance and evaluated the eddy coefficient by expressing Eq. 14 in the finite-difference form:

$$\epsilon = \frac{2 \Delta x s_x U}{s_x + \Delta x - s_x - \Delta x} \dots \dots \dots \quad (15)$$

In Eq. 15 2 Δx delineates a finite section of estuary over which the salinity may be assumed to vary linearly. The mean concentration over this section is s_x and the mean velocity U . The denominator is the difference between the concentrations at the limits of the section. For the type of estuary considered, the concentration at the seaward end is greater than at the river end and ϵ is always positive. At both the head and the mouth of the estuary the gradient approaches zero and neither Eq. 14 nor 15 is appropriate. In this work, the assumption is made that the diffusivity and velocity do not vary with distance over the section of the estuary considered. The error introduced by this approximation may be determined by comparing the value of the eddy diffusivity as calculated by Eq. 15 and by the integrated form of Eq. 14. Assuming constant coefficients in this equation, integration leads to:

May, 1960

in which s is the salinity at distance x , and s_0 is the salinity at $x = 0$. A plot of the logarithm of the saline or chloride concentration against an arithmetic distance scale will indicate a linear relation if the coefficients U and ϵ do not vary with distance. The slope of such a line is a measure of the ratio of these coefficients and ϵ may be evaluated graphically in this fashion. In some cases, the section of river under study may be above the intrusion of sea water and salinity data would not be available for evaluation of the turbulent transfer coefficient. In this case, any conservative property of the waste water, which significantly increases the river-water concentration, may be used to determine the eddy coefficient. A particularly appropriate characteristic is the concentration of a stable dissolved chemical ion. The solution proposed by Stommel⁸ is appropriate for this case:

$$\frac{s}{s_0} = \frac{1 - e^{-(U/\epsilon)x}}{(U/\epsilon)x_0} \quad \dots \dots \dots \quad (17)$$

in which s_0 is the upstream concentration of the conservative property, s denotes the downstream concentration of the conservative property, x_0 is the distance from the mouth of the estuary or from the point where the concentration becomes constant to the point where concentration = s_0 , and x represents the distance from the mouth of the estuary or from the point where the concentration becomes constant to the point where concentration = s , the distance measured negatively from the mouth or from the point of constant concentration.

The flow velocity, U , may be calculated directly from the continuity equation

in which Q is the river discharge and A is the cross-sectional area. It is probable that the velocity will also vary with distance, decreasing in the downstream direction. The error introduced by assuming an average value may be determined, as in the case of the eddy diffusivity. Frequently, the value of this velocity is so small that no significant error is introduced in the oxygen calculations by this assumption. In any case, the cross-sectional area is frequently composed of two distinct areas: the relatively shallow lateral zone and the deep central channel zone. The quantity of flow in this latter zone is usually so much greater than in the lateral area that it may be appropriate in determining the velocity by means of Eq. 18 to employ only the central channel area. Each estuary must be evaluated separately in this regard and examination of the shape of the cross-sectional areas indicates the possibility of this channeling effect.

The reaeration coefficient may be determined from formulas which were developed specifically for non-tidal streams and rivers.¹⁵ The mathematical

model proposed for the non-tidal bodies may be applied to estuaries. The basic relationship for the reaeration coefficient is

$$K_2 = \frac{[D_L r]^{1/2}}{H} \dots \dots \dots \quad (19)$$

in which D_L is the molecular diffusivity of oxygen, r denotes the rate of surface renewal, and H is the average depth of the section. The surface renewal rate was defined by the ratio of the time averages of the velocity fluctuation and mixing length in the vertical plane. This ratio is equal to the velocity gradient at the water surface for a condition of non-isotropic turbulence. This parameter probably defines the surface renewal for a vertically stratified estuary, in which there are pronounced differences in the velocity with depth. For a non-stratified estuary, however, the velocity field is reasonably uniform in the vertical plane. For this case, the vertical velocity fluctuation and the mixing length were taken to be equal to one-tenth of the forward flow velocity and average depth. These values were reported as averages from measurements taken in tidal bodies.^{18,19} It is significant to note that these ratios are of the same order of magnitude as in non-tidal rivers. Substituting the ratio of the average velocity and average depth for the rate of surface renewal, the reaeration coefficient becomes:

$$K_2 = \frac{[D_L U_o]^{1/2}}{H^{3/2}} \quad \dots \dots \dots \quad (20)$$

The velocity U_0 refers to mean tidal velocity over a complete cycle. This velocity is usually more significant than that due to river discharge. The depth refers to the average over the section and over a cycle. If both the tidal velocity and the depth vary considerably with distance, then short stretches must be taken over in which the variation is minimal.

The evaluation of the rate of deoxygenation may be carried out in a manner similar to that of the eddy diffusivity. Assuming representative values of the eddy diffusivity and the velocity are available, the value of the deoxygenation coefficient, K_d , may be obtained from Eq. 4. The logarithm of the concentration of organic matter (BOD) is linear with distance for the stated conditions. The slope of the line defining this relation is a measure of the exponent in Eq. 4, from which K_d may be calculated. In assigning a value of K_d to represent the decay of organic matter, distinction should be made between the removal of organic matter and the rate of deoxygenation. In the above equation, it has been assumed that the rate of removal of organic matter is equal to the rate of deoxygenation. If BOD is being removed by other mechanisms, such as sedimentation, which do not utilize oxygen, then the coefficients associated with BOD must take this difference into account. In such a case, the designation of K in Eqs. 3 and 4 becomes K_f to indicate total removal of BOD. In Eq. 8 and the subsequent equations which describe the oxygen balance, the K_d is appropriate. If no other processes are involved in the removal of BOD, the K_d will

18 "Theoretical Considerations of the Motion of Salt and Fresh Water," by J. B. Schiff and J. T. Schonfeld, Proceedings, Minn. Internat'l. Hydr. Convention, September,

19 "Density Current Problems in an Estuary," by T. Hamada, Proceedings, Minn. Internat'l. Hydr. Convention, September, 1953.

equal K_r . These factors have been described²⁰ and examples of their application presented.²¹

COMPARISON OF THE CALCULATED AND OBSERVED PROFILES

In order to verify the proposed formula, comparisons are made between the calculated profiles and values measured in estuarine pollution surveys. These comparisons may be made on both the BOD decay (Eq. 4) and the DO balance (Eq. 8). These equations are based on steady state conditions and for a valid comparison, the observed data should be representative of such a condition. Sampling should be performed simultaneously at a series of stations along the estuary when the variations of tidal motion, flow, temperature and waste discharge are minimal. This steady state condition is maintained at high or low water slack, as shown in Fig. 1, for a period of 1 hr to 3 hr depending on the type of tide. Appreciating these factors, A. J. Kaplovsky conducted and reported estuarine surveys of the lower Delaware River using the "same slack" technique.^{22,23} Prior to these surveys, Kaplovsky had conducted intensive sampling at various stations over the width and the depth of the cross section. Sampling was carried on at low and high water slack periods. Inspection of these data indicate no definite pattern of variation of DO and BOD in the lateral and vertical planes. The variation of the BOD within each set at any slack period was greater than that of the DO. The variation of the latter was minimal. Kaplovsky compared the data from the cross-sectional series and the "same slack" series and concluded that the latter were more representative of the actual conditions. Six surveys were conducted and of these three provided the complete information for a comparison between the calculated DO profile and the observed values.

Prior to the time the Delaware River work was reported, the Water Control Board of the State of Virginia conducted surveys on the Lower James River, which is subject to the tidal action of the Chesapeake Bay. Eleven surveys were run during the months of August and September.²⁴ Although the data are not as reliable a measure as those from a survey of a "same-slack" period, the average results do provide a sufficiently representative pattern to justify a comparison between the calculated DO profile and the observed results. Intensive cross-sectional sampling was also conducted.

In order to calculate a dissolved oxygen profile, knowledge of the various coefficients, representing the velocity term, the eddy diffusivity and the coefficients of deoxygenation and reaeration, is necessary.

Calculation of the Velocity Term.—The value of the velocity used in the oxygen-balance equation is the seaward velocity due to the river discharge. In the case of the Delaware, the cross-sectional area used in this calculation was that of the ship channel. Based on Pritchard's observations, Kaplovsky estimated that the channel, which occupied approximately 70% of the cross-sectional

20 "Pollution Load Capacity of Streams," by H. A. Thomas, Jr., Water and Sewage Works, Vol. 95, November, 1948.

21 "Assimilative Capacity of Natural Rivers," by D. J. O'Connor, Proceedings, Manufacturing Chemists Assn., 1959 (in press).

22 "Investigation of Sanitary Water Quality in the Lower Delaware River," by A. J. Kaplovsky, Tech. Report II, Water Pollution Comm., State of Del., December, 1956.

23 "Estuarine Pollution Surveys," by A. J. Kaplovsky, Sewage and Industrial Wastes Journal, Vol. 29, September, 1957.

24 "Lower James River Pollution Study," Water Control Bd., Commonwealth of Va., 1951.

area, carried more than 90% of the waste. The river discharge at a specific station was determined by multiplying the flow at Trenton, N. J., by the ratio of the drainage area at that station to that at Trenton.

The cross sections of the James River are characterized by littoral areas of about 4 ft in depth and a main channel of approximately 20 ft in depth. The majority of the flow was restricted to the latter zone, similar to that of the Delaware. The area of the main channel and adjacent littoral area up to 4 ft in depth were taken as the flow area. As in the case of the Delaware River, the flow area was approximately 70% of the total cross-sectional area. The velocity term was determined by means of Eq. 18. The river discharge, Q , was taken as the average value of a period of about 2 weeks preceding the survey date.

Evaluation of the Eddy Diffusivity.—In the mathematical development, it was assumed that the coefficient of eddy diffusion remained constant over the section of the estuary under consideration. If this assumption is valid, then a plot of the logarithm of the chloride concentration with an arithmetic scale of distance yields a straight line. For the Delaware River, the approximate linearity of this relationship is indicated in Fig. 3. The line is fit by eye and the coefficient of eddy diffusion is calculated in accordance with Eq. 16.

In the case of the James River, the salt water intrusion did not extend into the zone of the DO sag curve. Consequently, the chloride concentrations could not be used in the determination of the eddy diffusion coefficient. It was fortuitous that one of the industrial discharges contain a significant quantity of sulfate concentration and the measured values of sulfate ion were used in the determination of the diffusion coefficient, by means of Eq. 17. Analysis of the sulfate data indicated x_0 may be taken as 20 miles.

Assignment of the Coefficient of Deoxygenation.—This coefficient may be determined in a manner similar to that of the eddy diffusivity. Having calculated the velocity and eddy diffusivity, as indicated previously, and having available measured values of BOD at various estuarine stations, the value of the deoxygenation coefficient may be obtained from Eqs. 4 and 5. The logarithm of BOD is plotted against an arithmetic scale of distance and a line of best fit approximated by eye. The slope of the line is a measure of the exponent in Eq. 4 and the coefficient of deoxygenation is calculated from Eq. 5. This relationship is shown in Fig. 3 for the Delaware River and Fig. 4 for the James River. The river-water temperatures are also indicated in these figures. In calculating this coefficient for other sets of data at different temperatures, the above procedure was followed and, in addition, the following temperature correlation was used:

$$K_T = K_{20} (1.047)^{T-20} \dots \dots \dots \quad (21)$$

in which K_{20} is the coefficient at 20°C , K_T denotes the coefficient at $T^{\circ}\text{C}$, and T is the temperature, in degrees Centigrade. Each set of data is consistent with respect to temperature within the group of each river. Because of the erratic nature of the decrease in BOD, this coefficient proved to be the most difficult to define. Trial-and-error computations were necessary in order to achieve this consistency.

Determination of the Reaeration Coefficient.—From extensive measurements of cross-sectional areas of both rivers by the Corps of Engineers, average depths were calculated. The value used in Eq. 20 was the average of the flood and ebb conditions. The mean tidal velocities over a cycle were taken from

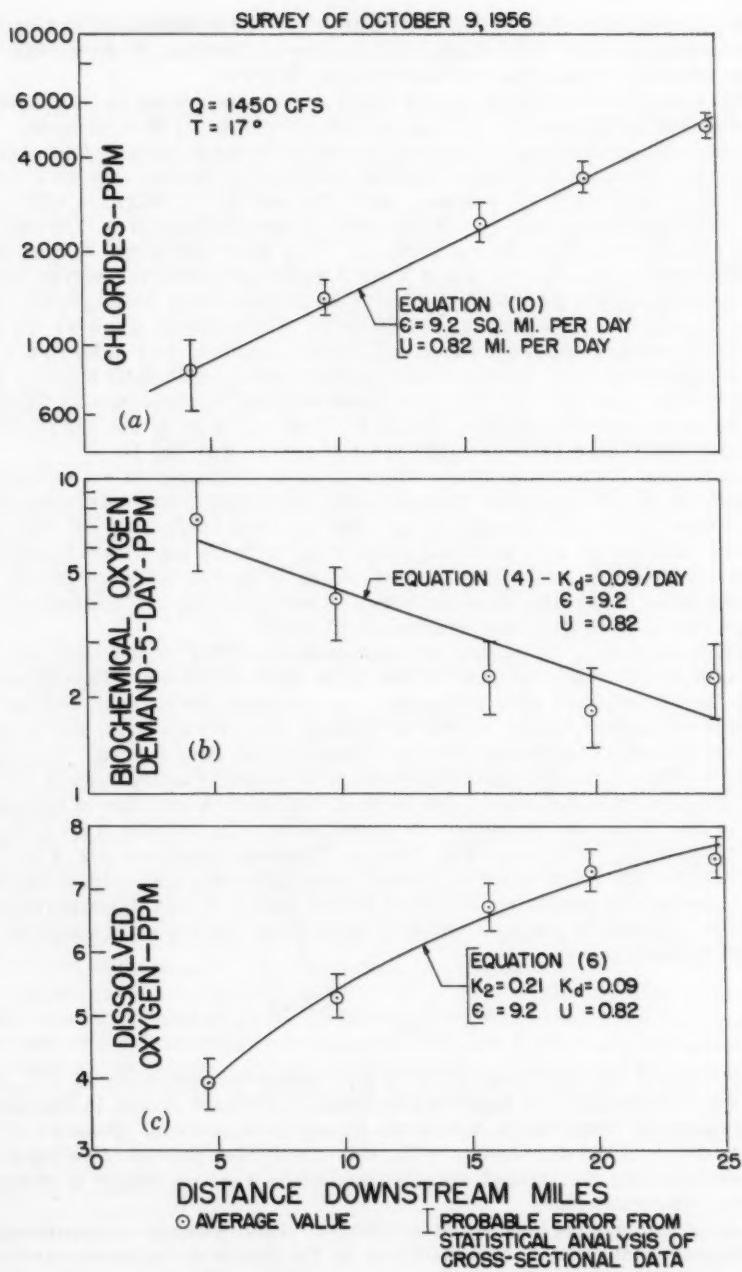


FIG. 3.—CHLORIDE, BOD, AND DO PROFILES
FOR THE DELAWARE RIVER

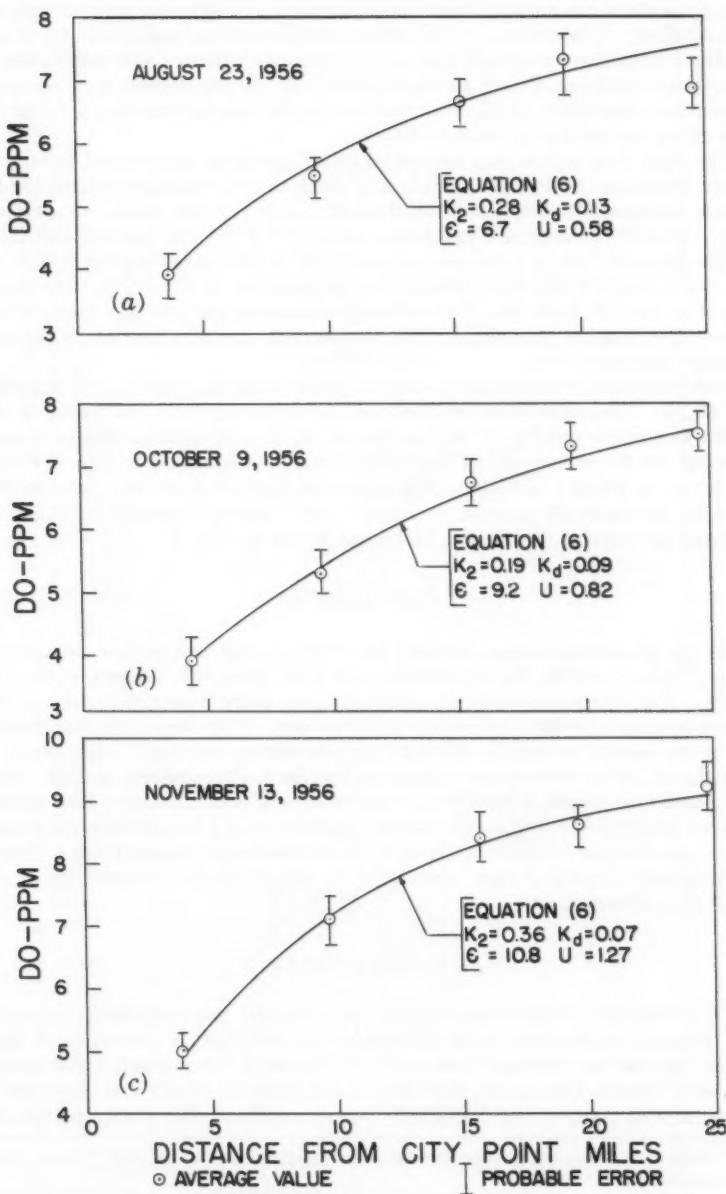


FIG. 4.—TYPICAL PROFILES OF THE DELAWARE RIVER

the tidal current data of the United States Geodetic Survey. The oxygen diffusivity was taken at 20°C and the reaeration coefficient computed for this temperature. Conversion to the other temperatures was made by means of Eq. 21. It is pertinent to note that one survey of Delaware was conducted while an average wind velocity of 15 mph prevailed. An adjustment was made in the reaeration coefficient to allow for the increased oxygen transfer induced by the wind effect on the water surface.²⁵

The final step before calculation of the DO profiles is the assignment of ultimate BOD and the initial DO deficit. The former is calculated from the 5-day values, knowing the laboratory coefficient. The average factor converting the 5-day value to the ultimate value was taken at 1.3 for the Delaware²⁶ and 1.67 for the James²⁷ which were determined from a series of long-term BOD tests. The 5-day value which was used in the calculation of the DO profile was read from the line of best fit. The initially dissolved oxygen was taken from the survey data and the saturation value is available for the given temperature and chloride concentration.

With these data, the dissolved-oxygen profiles were computed in accordance with Eq. 8. The calculated profiles and the observed data are shown in Fig. 3 for the Delaware and Fig. 4 for the James. In Fig. 5, similar comparisons are made for the three surveys of the Delaware in which complete information was available. In Table 1 are shown the associated coefficients and data, as determined by the methods outlined in steps 1 to 4. Similar comparisons are made for three surveys of the James River, as shown in Fig. 6.

CONCLUSIONS

The proposed formulas defining the BOD decay and oxygen balance in an estuary agree reasonably with observed data from the Delaware and James Rivers. The dissolved-oxygen profiles are more consistent and in better agreement than the BOD decay for these rivers. This work further confirms the "same-slack" technique of conducting estuarine surveys. Additional survey data of other rivers are required to test the theoretical model. Future work should be directed toward an analysis of the conditions which allow for variable coefficients in the differential equation and a non-steady state toward more accurate and reliable methods of field determinations and measurements. The proposed formulas may also apply to upland rivers in which longitudinal diffusion is pronounced.

ACKNOWLEDGMENTS

The assistance of the following men is gratefully acknowledged and appreciated: Francis Taylor and Anthony Ventriglia, Associate Professors of Mathematics, Manhattan College, who checked some of the mathematical development; and Thomas Gallagher, A.M. ASCE, and John St. John, who compiled data and calculated many of the dissolved-oxygen profiles. The participation of the

²⁵ "Effects of Winds on the Oxygen Transfer Coefficient," by D. J. O'Connor, unpublished manuscript.

²⁶ A. J. Kaplovsky, Water Pollution Comm., State of Del., private communication, 1958.

²⁷ A. L. Paessler and D. Aderholt, Water Control Bd., Commonwealth of Va., private communication, 1959.

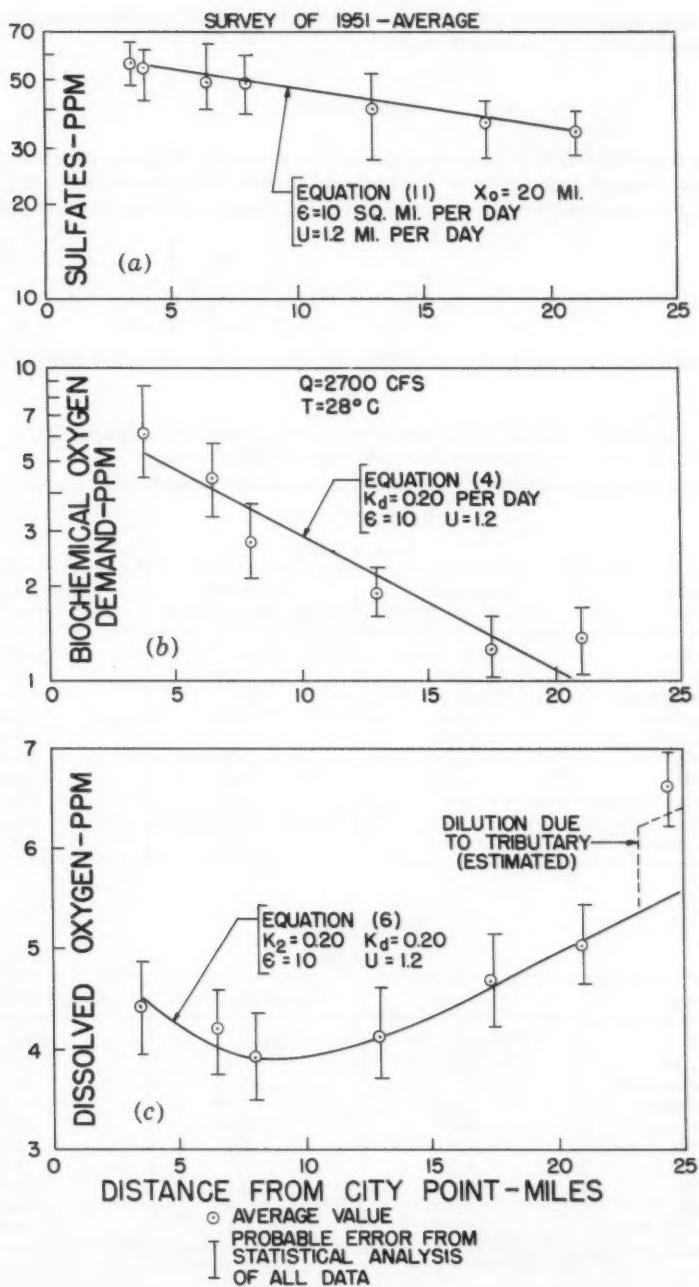


FIG. 5.—SULFATE, BOD, AND DO PROFILES FOR THE JAMES RIVER

latter was sponsored by a grant from the National Science Foundation for student participation in research work.

APPENDIX I

The coordinates of the point of minimum dissolved oxygen, usually referred to as the critical point, may be derived as follows: Differentiation of Eq. 8 and equating to zero yields the expression for the distance to the critical point:

$$x_c = \frac{1}{j_1 - j_2} \log_e \frac{j_2}{j_1} \left[1 - \frac{D_0}{L_0 F} \right] \dots \dots \dots \quad (22)$$

The expression for the minimum deficit is obtained by taking the second deriv-

TABLE 1.—BASIC DATA USED IN CALCULATION OF ESTUARINE DISSOLVED OXYGEN PROFILES

DELAWARE RIVER

Data of 1956

Survey Tide	August 23 Low Water Slack	October 9 Low Water Slack	November 13 High Water Slack
Q - CFS	5300	7450	11,600
U - Mi. PD	0.58	0.82	1.27
T - Centigrade	25	17	12
Kd - Per Day	0.13	0.09	0.07
K ₂ - Per Day	0.28	0.19	0.36
C _s - PPM	8.1	9.4	10.4
Co - PPM	4.1	3.9	5.0
L ₅ - PPM	3.5	6.3	9.5
Lo - PPM	4.6	8.2	12.4
- Sq. Mi. PD	6.7	9.2	10.8

JAMES RIVER

Data of 1951

Survey	Average	August 20, 21, 22	August 27, 28, 29
Q - CFS	2700	3150	2350
U - Mi. PD	1.2	1.4	1.05
T - Centigrade	28	30	26
Kd - Per Day	0.20	0.22	0.18
K ₂ - Per Day	0.20	0.20	0.17
C _s - PPM	7.7	7.5	8.0
Co - PPM	4.5	5.0	3.4
L ₅ - PPM	5.4	6.0	3.6
Lo - PPM	9.0	10.0	6.0
- Sq. Mi. PD	10.0	11.5	9.0

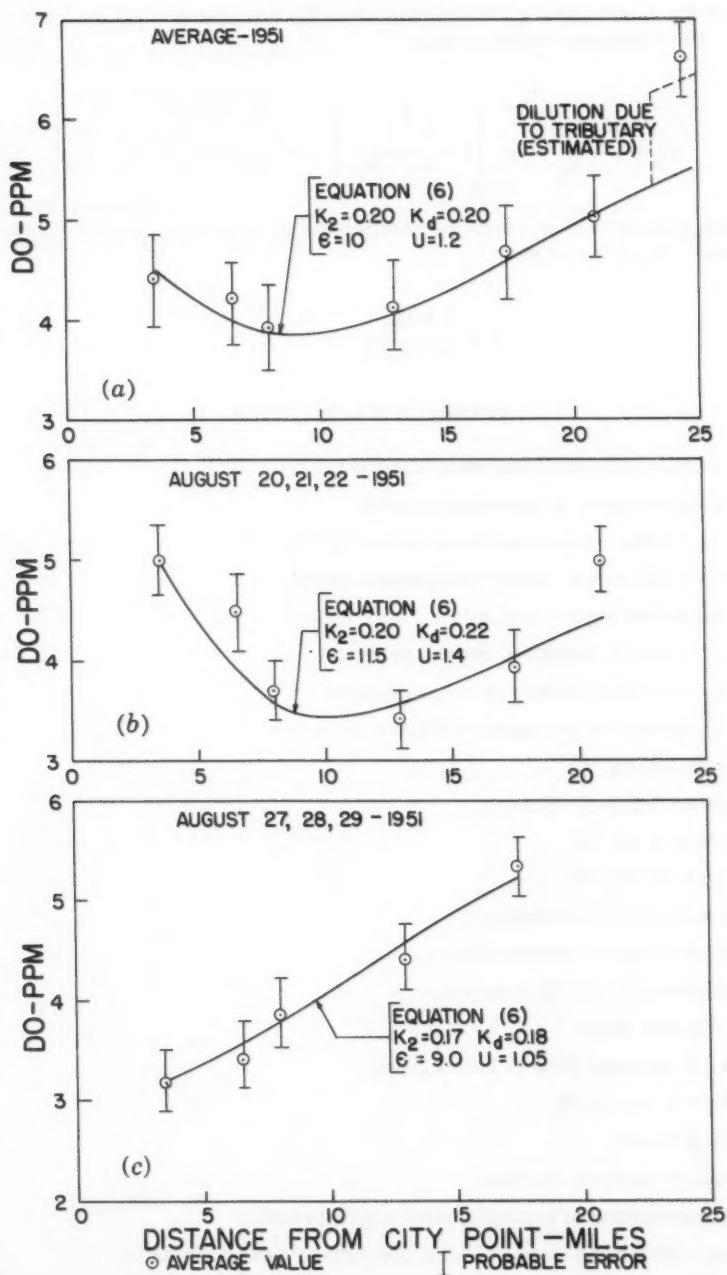


FIG. 6.—TYPICAL DO PROFILES OF THE JAMES RIVER

ative of Eq. 8, substituting this derivation in Eq. 6 and permitting dc/dx to equal zero. The minimum deficit equals:

$$D_c = \frac{K_d L_0 e^{j_1 x}}{K_2} \left[1 + \frac{j_1^2 \epsilon}{K_2 - K_d} \right] - \frac{\epsilon j_2^2 e^{j_2 x}}{K_2} \left[F L_0 - D_0 \right] \dots (23)$$

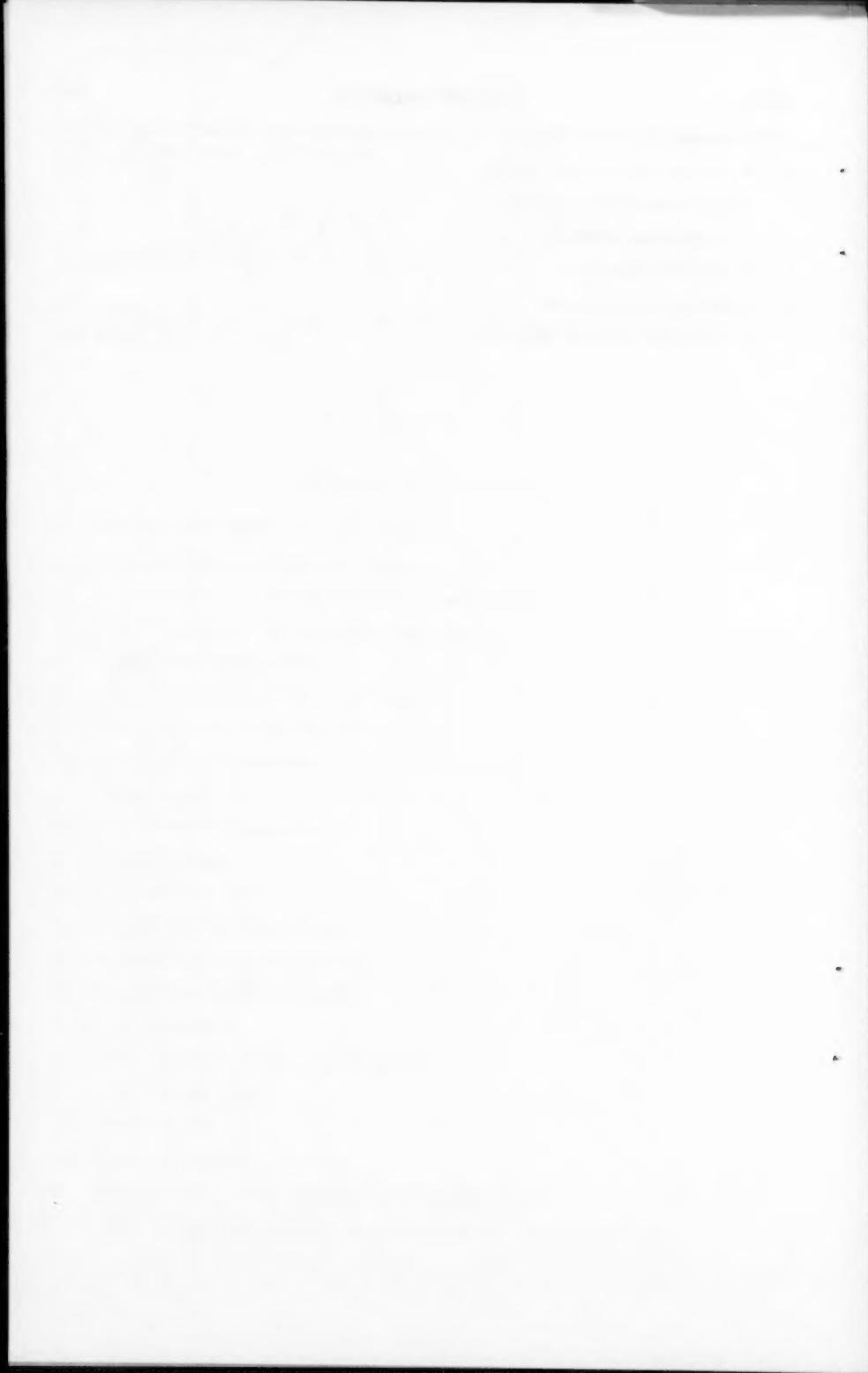
For the special case in which the coefficients of reaeration and deoxygenation are equal, Eq. 8 becomes:

$$D = \frac{K x L_0}{U - 2 \epsilon j} e^{jx} + D_0 e^{-jx} \dots \dots \dots (24)$$

APPENDIX II.—NOTATION

- A = mean cross-sectional area of estuary;
- c = concentration of dissolved oxygen;
 - c_0 = initial concentration of dissolved oxygen;
 - c_s = saturation value of dissolved oxygen;
- D = dissolved oxygen deficit;
 - D_0 = initial dissolved oxygen deficit;
 - D_c = critical dissolved oxygen deficit;
- D_1 = coefficient of molecular diffusion of oxygen;
- F = term in Eq. 9;
- H = mean depth of estuary;
- j_1 = term in Eq. 5;
- j_2 = term in Eq. 10;
- K_2 = coefficient of reaeration;
- K_d = coefficient of deoxygenation;
- K_r = coefficient of BOD removal;
- L = ultimate BOD;
 - L_0 = ultimate BOD at initial point;
 - L_5 = 5-day BOD;
- Q = land runoff;
- r = rate of surface renewal;
- s = concentration of a conservative characteristic;
 - s_0 = initial concentration of a conservative characteristic;

- T = temperature, Centigrade;
U = velocity due to land runoff;
 U_0 = mean tidal velocity;
x = longitudinal distance;
y = vertical distance;
z = lateral distance; and
 ϵ = coefficient of eddy diffusion



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Proceedings of the American Society of Civil Engineers

BEHAVIOR OF SUSPENSIONS

By A. W. Bond¹

SYNOPSIS

There is developed a theory of the settling of suspensions in still water and of the behavior of suspensions in an upflow. The theory is examined with experiments on the settling of alum and lime hydroxide floc suspensions, and of their behavior in an expanding upflow. Their behavior is compared in still water and in upflow, and there is discussed the application of the theory to the precipitates formed in sedimentation basins.

INTRODUCTION

The early work on the theory of settling concerned itself chiefly with the rate of fall of heavy particles in still water, and the modifications due to horizontal flow, and some work has been done on the settling of light floc particles.

Any attempt to correlate the behavior of such floc particles in still water with that in a horizontal flow basin was defeated by the existence of random currents of much greater velocity than the settling velocity of the particles. The elimination of this unpredictable factor with the introduction of upflow basins has stimulated interest and study in this field of enquiry.

Note.—Discussion open until October 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SA 3, May, 1960.

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THE PHENOMENA OF SETTLING

Settling of Individual Particles in Still Water.—As a particle falls, it is subjected to a viscous drag by the surrounding liquid, which opposes the force of gravity. In addition, the particle continuously displaces the liquid below it; the displaced liquid flows upwards and around it, and by its upward velocity increases the drag. As the particle accelerates and its velocity of fall increases, the drag also increases until it balances the force of gravity, after which the particle settles with a uniform velocity.

The well known Stokes' Law is useful for calculating the settling velocity of spherical particles, but does not afford a practical method of evaluating that of the individual particles of the precipitates formed in sedimentation basins. Although under certain conditions such particles are fairly uniform in size and regular in shape, they lose all uniformity and regularity if an attempt is made

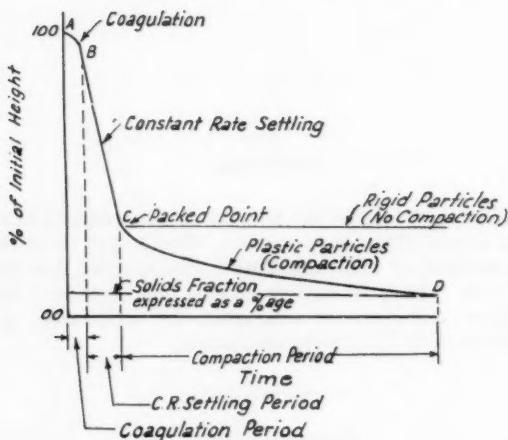


FIG. 1.—HEIGHT-TIME SETTLING CURVE FOR A HYDROXIDE SUSPENSION.

to separate them from their neighbors for study, and a different method of approach must be devised.

Settling of Rigid Particles.—If a suspension of discrete particles is allowed to settle in a still water, it will be observed that the top of the suspension falls at a uniform rate (BC, Fig. 1) until all the particles are deposited on the bottom of the container. If the particles are rigid, they will pack on the bottom as closely as their shape will permit, and then, of course, compact no further.

Settling and Compaction of Plastic Particles.—A suspension of plastic particles, for example, hydroxide floc, behaves in a similar way. For a relatively short time, the top of the suspension falls at a uniform rate in the same manner as rigid particles (BC, Fig. 1). The suspension is settling. At the end of this time, when all have reached the bottom, the top of the suspension still continues to fall, but at a gradually decreasing rate (CD, Fig. 1) and finally comes to rest. The particles have been compacting during this latter stage.

Constant Rate Setting and Compaction Periods.—The relatively short time of fall at a constant rate is known as the constant rate settling period.² The relatively long time of fall at a gradually decreasing rate will be referred to as the compaction period. The laws governing the behavior of a suspension of plastic particles during the two periods are quite different.

In this paper, attention will be given only to constant rate settling.

Hindered Settling.—In a suspension in which the particles are widely separated, that is, one in which the concentration is low, a particle will not be affected by its neighbors, but will fall at the same rate as an isolated individual particle. As the concentration increases, the particles will begin to restrict the area through which the displaced liquid flows up; the velocity of this liquid will increase, and the particles will settle at a lower velocity. This phenomenon is known as hindered settling. It will be demonstrated that there is a definite relation between the concentration of the suspension and its settling velocity during the hindered or constant rate settling period.

THEORY OF SETTLING

Interparticle Velocity.—The upward velocity of the liquid between the particles will be called the interparticle velocity. It can be expected to have a definite value for any given concentration of particles of a particular shape and size. The true interparticle velocity has both horizontal and vertical components, both of which will vary locally according to the random disposition and movements of the particles. As the suspension as a whole is in a state of equilibrium in any horizontal plane, the horizontal drag on any particle, as a statistical average, is zero. The term, interparticle velocity, as used here, will be understood to mean the average vertical component of the true interparticle velocity.

Relative Velocities.—Let the settling velocity of an individual particle in still water, unhindered by neighbors, be V_p relative to an external frame.

Consider a suspension of such particles, which is settling as a unit at velocity V_S and let the interparticle velocity be V_p , both relative to the same external frame. The viscous drag and the force due to gravity, acting on each individual particle, will still balance, and hence the settling velocity of each individual particle, relative to the upflowing liquid will remain the same V_p . Relative to the external frame, however, the settling velocity of each individual particle will be reduced by an amount equal to V_D and it will fall at a uniform velocity $V_p - V_D$.

This is the same velocity V_S as the rest of the suspension, that is,

The Relation between Settling Velocity and Concentration.—Let the mean dimension of the particles be d and let there be n particles in each short length l in each direction parallel to the axes of the three-dimensional rectangular co-ordinate system. Then in any horizontal area l^2 , the area of the particles will be $f_1 n^2 d^2$ and in any volume l^3 the volume of the particles will be $f_2 n^3 d^3$ where f_1 and f_2 are constants depending on the shape of the particles.

² "Settling Characteristics of Suspensions in Water Treatment Processes," by A. A. Kalinske, Journal, Amer. Waterworks Assn., Vol. 40, No. 113, February, 1948.

It is seen at once that the concentrations of particles may be measured by

Consider the motion relative to the suspension. The relative interparticle velocity will be $V_S = V_D = -V_p$ and the relative velocity of the clear liquid above and below the suspension will be V_S .

The rate of flow of liquid q passing any horizontal plane fixed relative to the suspension, whether through, or above, or below it, will be constant. Hence

Therefore

$$V_S = V_P \left(1 - f_1 \frac{n^2 d^2}{l^2} \right) \dots \dots \dots \quad (4)$$

But

Therefore

where f is a constant depending on particle shape.

The settling velocity of a suspension during the constant rate period is thus a function of the settling velocity of individual particles and of their concentration. At a low concentration of solids, the settling velocity of the suspension approximates that of individual particles, which, after all, is self evident. As the concentration increases, the decrease in the settling velocity of the suspension is in direct proportion to the two-thirds power of the concentration.

Since the validity of this will be demonstrated with such an unlikely material as hydroxide floc, it is reasonable to expect that discrete particles of any material, whose density is greater than that of the liquid in which they are suspended, will have a hindered settling velocity depending upon their concentration, as given by Eq. 6.

Other Derivations.—A. A. Kalinske² has deduced, from some settling experiments, quoted by him, with alum floc and calcium carbonate crystals, the following empirical velocity-concentration relation:

Besides being empirical, the equation is not dimensionally homogeneous. N. D. R. Schaafsm^a³ has developed theoretically the relation

and has obtained good experimental agreement with alum floc. Eq. 8 is dimensionally homogeneous, but it is believed that the exponent of s should be 0.67, as in Eq. 6, and confirmed experimentally with hydroxide floc suspensions settling in still water and suspended in an upflow.

Commencement of Hindering.—According to Kalinske² settling commences to be hindered when the solids in a suspension occupy about 1% of the original volume of the mixture, and that, by weight, this point is reached when there are about 1,000 parts per million of silt or calcium carbonate crystals in a suspension in water, but at a very much lower concentration by weight for aluminium, iron, or magnesium hydroxide floc.

T. R. Camp,⁴ referring apparently to hydroxide suspensions, states that hindering commences when the volumetric concentration exceeds 0.5%.

G. M. Fair⁵ states that hindered flow persists in sand as long as the volumetric concentration of the sand grains exceeds 4.8%.

It would appear, however, from Eq. 6 that it is probably not legitimate to say that there is any definite minimum value of the concentration at which hindered settling commences.

EXPERIMENTAL METHODS AND RESULTS

Concentration of Solids.—The foregoing theory, as expressed by Eq. 6, was suggested by and devised to explain the results of experiments with hydroxide floc suspensions to be described subsequently. It is necessary, therefore, first to define the term "concentration" and describe the means used to measure it, for such materials. There are two methods:

1. Wet Solids Fraction.—This is the ratio, expressed as a decimal fraction, of the volume of the wet, settled solids to the original volume of the suspension. It was measured, in these experiments, by allowing the solids to settle for 24 hr in a graduated glass cylinder, $1 \frac{1}{8}$ in. diameter, the solids being gently stirred with a fine straw several times during that period. Further slight settling occurs about 24 hr, and the results may be slightly affected by the cylinder diameter, or by differences in technique, so that standard conditions and procedure must be used to obtain consistent results.

As the precipitates with which the tests were made are hydrous, and the amount of hydration may vary somewhat, this method of measuring the concentration of solids is not strictly accurate. It is, however, sufficiently so for use in water treatment work, and it is simple and convenient, assists in visualizing

³ "Bezenking als onderdeel van der waterzuivering," by N. D. R. Schaafsma, *De Ingenieur*, Vol. 62, No. 4, January, 1950, p. 61.

⁴ "Sedimentation and the Design of Settling Tanks," by T. R. Camp, Transactions, ASCE, Vol. 111, 1946, p. 895.

⁵ "The Hydraulics of Rapid Sand Filters," by G. M. Fair, Journal, Inst. of Water Engrs., Vol. 5, No. 2, March, 1951, p. 117.

the phenomenon of settling, and has the great advantage of being a natural measure of the conditions which actually obtained in the various parts of the treatment works.

2. Dry Solids Concentration.—The solids are settled, dried and weighed, and the concentration c expressed in units of weight per unit volume of the original suspension (usually pounds per cubic foot).

The wet solids fraction s is, it is stated,² a function of the concentration of the solids by weight, and may be expressed as

$$s = m \cdot c^r \quad (9)$$

Where m is a constant dependent on particle size, and r is close enough to unity to be disregarded for most practical purposes.

Settling Experiments.—Preliminary tests were made with suspensions of alum floc and lime floc, produced in a model upflow tank. In each series, the solids fraction of the samples varied from about 0.06 to about 0.33. A 100-ml graduated glass cylinder $1\frac{1}{8}$ in. diameter was filled to the 100-ml mark with the suspension, thoroughly shaken, placed upright, and the fall of the top of the suspension past each 5-ml or 10-ml mark timed with a stop watch. The sample was again shaken and the test repeated two or three times. The temperature of the sample was noted in each case. The results were then plotted as a height-time settling curve, a diagrammatic representation of which is shown in Fig. 1. The settling velocity is, of course, given by the slope of the curve.

At first (A to B) the particles are small and the settling velocity low. Coagulation commences, the particles increase in size, they accelerate and their settling velocity increases until at the end of 50 or 60 sec (B) coagulation and acceleration are complete, and the particles settle at a constant rate (velocity) for a time.

Suspensions with a solids fraction less than 0.1 were difficult to test, especially at low temperatures, as some of the solids settled before coagulation was complete and the top of the settling solids was not clearly defined. At higher concentrations, the solids settled with a sharply defined top, although particles of all shapes and sizes could be seen within the mass, falling at greatly varying velocities, or even rising, due to the influence of the upward interparticle velocity. It is obvious that, at the top of the settling solids, the interparticle velocity suddenly ceases and the water above is still. Many particles may thus rise to the top of the suspension, and then fail to leave it. In fact, any particle whose velocity of fall is less than average, but greater than that of the suspension as a whole, will remain with it, at the top, and form a trap for even slower particles. The whole suspension thus settles as though it were all composed of the fastest particles in it.

The next series of tests was designed to establish the relation between settling velocity and concentration. Various random samples of alum and lime slurries were tested at normal (summer) temperatures. Examples are shown in Fig. 2, with the settling velocity of the suspension as ordinate and the two-thirds power of the solids fraction as abscissa. The graph of every test was a straight line of the form given by Eq. 6.

The greatest difficulty in obtaining consistent results was found to lie in the measurement of the wet solids fraction, and no progress was made until a standard technique was followed (Tables 1 and 2).

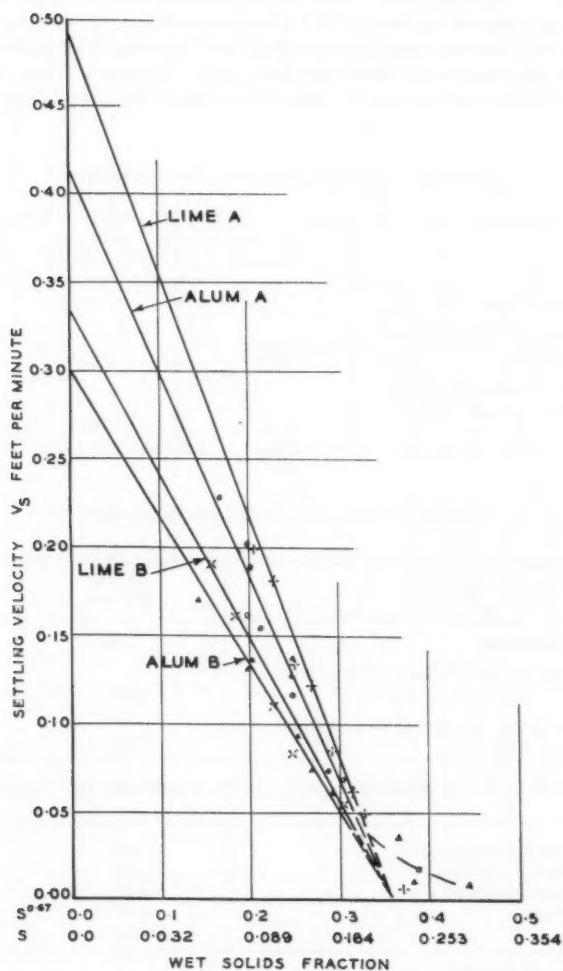


FIG. 2.—SETTLING VELOCITY-CONCENTRATION TESTS WITH RANDOM SAMPLES OF ALUM AND LIME SLURRY.

The Effect of Temperature on Settling Velocity.—Finally, a number of samples of alum and lime slurry of various concentrations were heated (or cooled) and a series of settling tests made of each sample as it cooled (or warmed). The results are plotted in Figs. 3 to 8 showing settling velocity as a function of temperature for various concentrations of six different floc suspensions.

Comments on Analyses.—All samples were obtained from slurry pools formed in a model upflow tank. The three alum samples (Figs. 3 to 5) con-

TABLE 1.—ANALYSES OF ALUM SLURRIES

	1st Run (Fresh)	2nd Run (Medium)	3rd Run (Aged)
Proportion of sediment	Low	Medium	High
Specific gravity of wet settled slurry (at 20°C.)	1.0400	1.0307	1.0243
Weight of dried solids per cubic foot of wet settled slurry (lb.)	4.61	3.68	2.97

TABLE 2.—ANALYSES OF LIME SLURRIES

	1st Run (Fresh)	3rd Run (Aged)
Proportion of sediment	Low	Low
Specific gravity of wet settled slurry (at 20°C.)	1.0279	1.0379
Weight of dried solids per cubic foot of wet settled slurry (lb.)	7.56	6.33
Chemical composition, calculated from analysis, in pounds per cubic foot of wet settled slurry.		
Magnesium hydroxide—Mg(OH) ₂	1.37	1.16
Calcium carbonate—CaCO ₃	5.07	4.22
Calcium hydroxide—Ca(OH) ₂	0.37	0.29
Minor constituents	0.75	0.64
Water	56.61	58.46

(No analysis was made of the second run slurry.)

tained successive increases of turbidity, whereas the three lime samples (Figs. 6 to 8) were free of turbidity.

The proportion of entrained water increased, and the density correspondingly decreased with age in both alum and lime slurry. The decrease in density, by itself, appears to result in a decrease of settling velocity, as shown by the lime tests.

The same effect would be expected to occur with alum slurry, but the increase in the proportion of sediment apparently has a greater effect on the

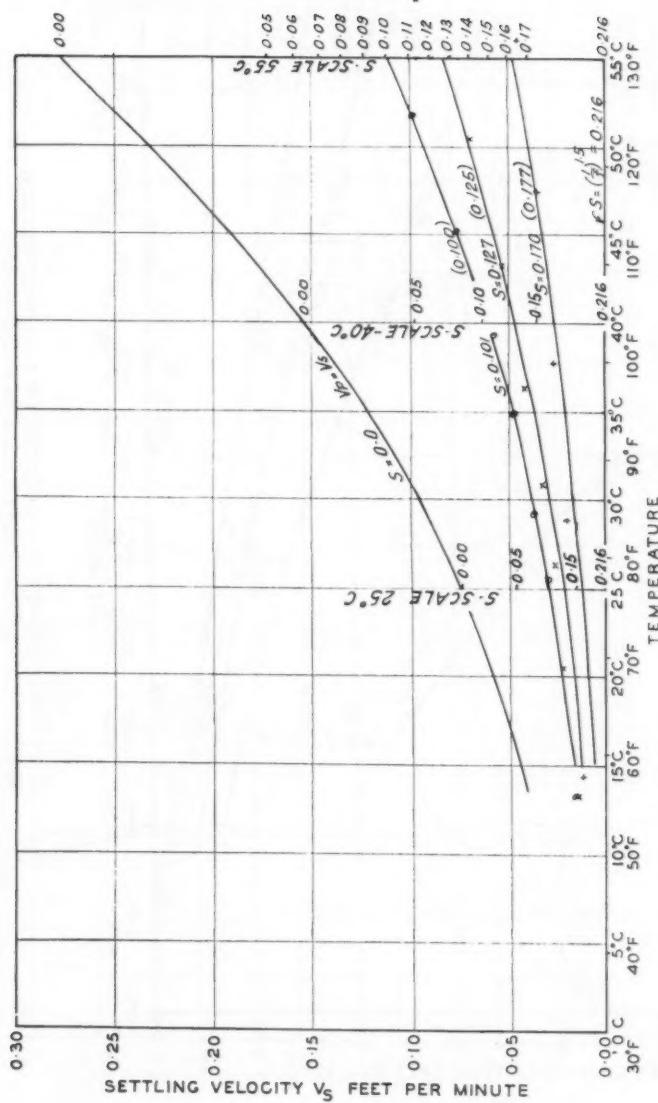


FIG. 3.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS CONCENTRATIONS OF FRESH ALUM SLURRY.

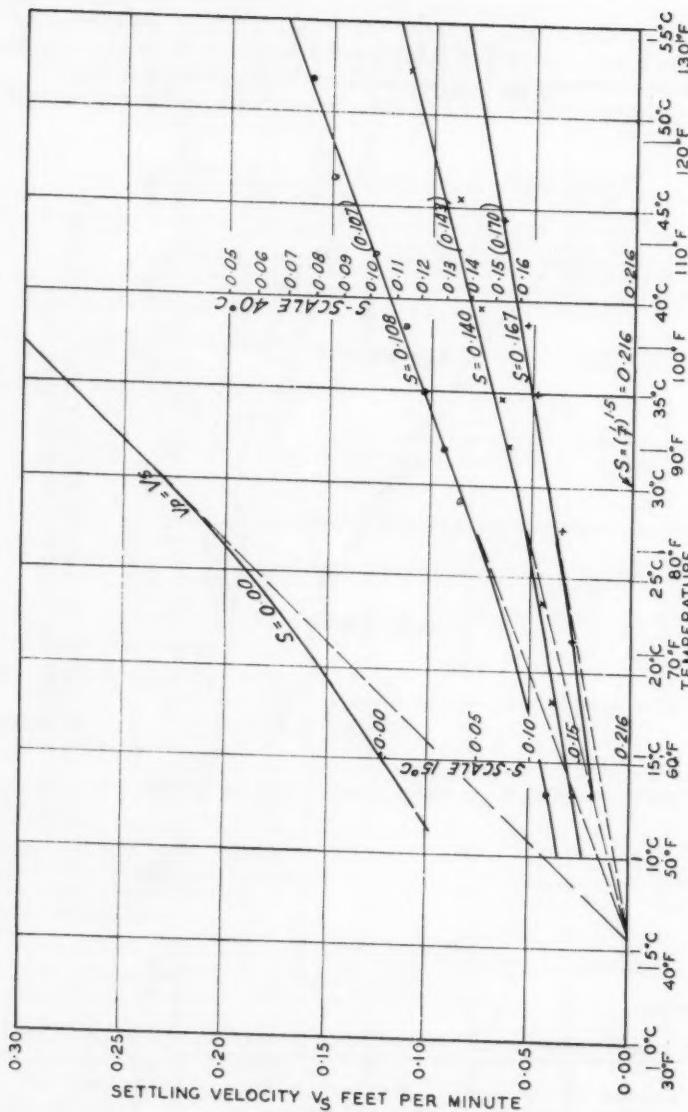


FIG. 4.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS CONCENTRATIONS OF MEDIUM ALUM SLURRY.

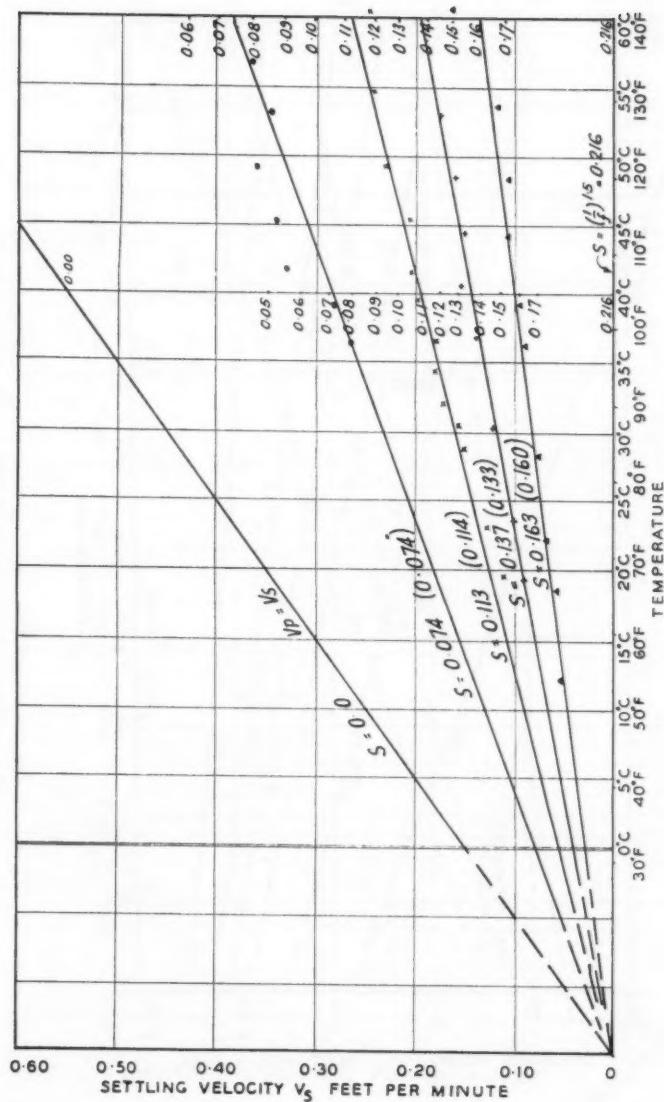


FIG. 5.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE
FOR VARIOUS CONCENTRATIONS OF AGED ALUM SLURRY.

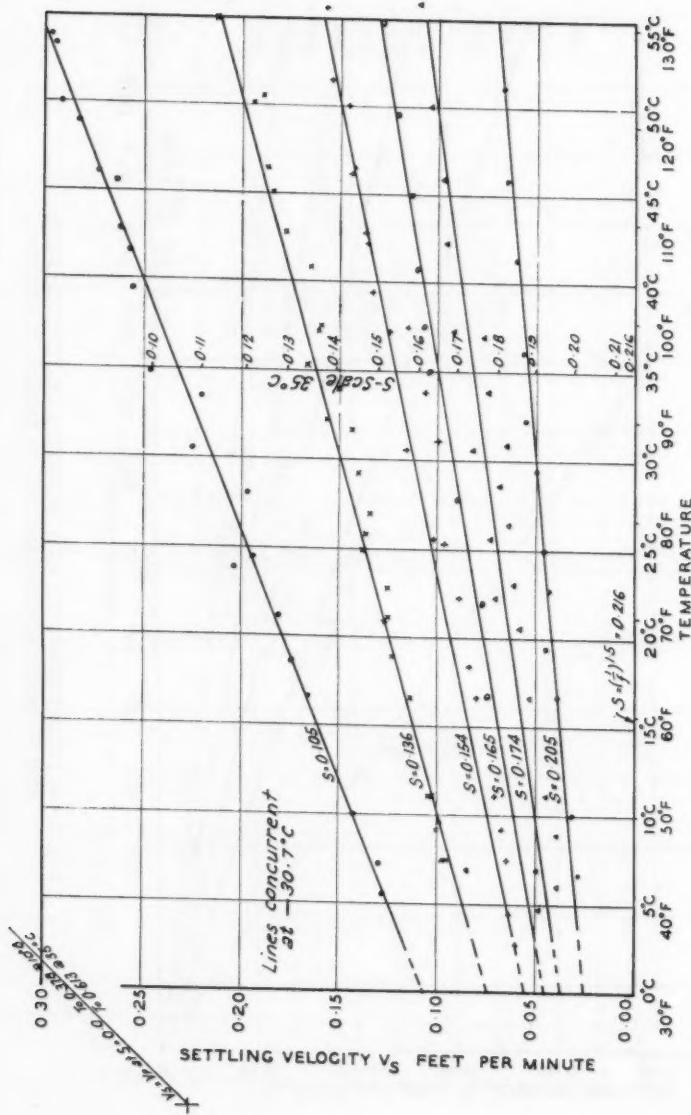


FIG. 6.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS CONCENTRATIONS OF FRESH LIME SLURRY.

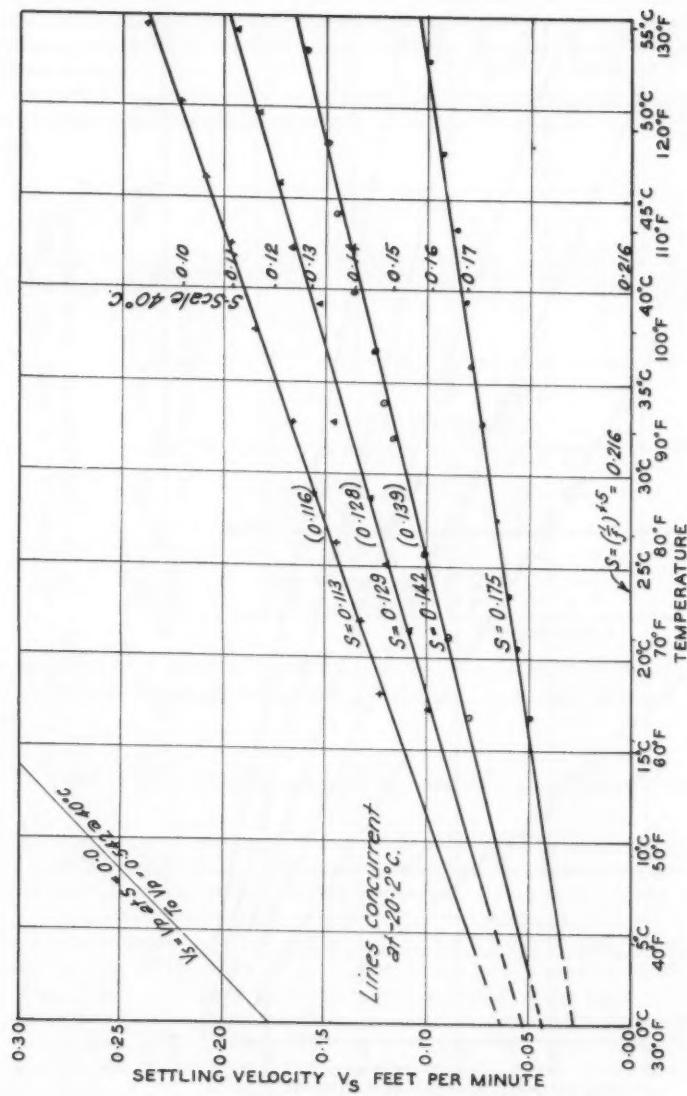


FIG. 7.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS CONCENTRATIONS OF MEDIUM LIME SLURRY.

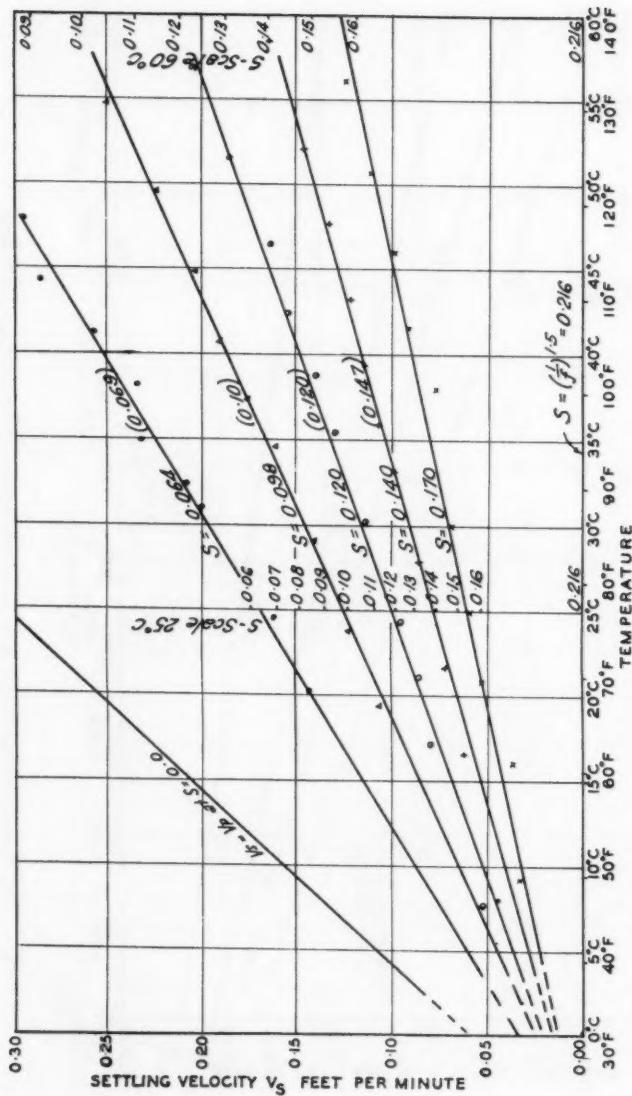


FIG. 8.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS CONCENTRATIONS OF AGED LIME SLURRY.

settling velocity than the decrease in density. Possibly this is due to a change in the shape of the particles, some of them becoming more compact, owing to the presence of heavy nuclei on which to coagulate. As previously noted, the settling velocity of a suspension tends to depend on that of the fastest particles, so that an increase in the number of heavy nuclei would lead to an increase of settling velocity.

Further work is required to confirm the foregoing results and assumptions and to distinguish between the effects of slurry density and proportion of sediment.

DISCUSSION

Settling Velocity as a Function of Temperature.—Consider now Fig. 9. At any temperature T , B is a point on the $V_S - T$ curve for a suspension with

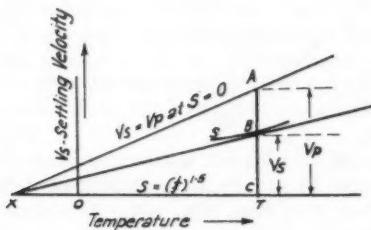


FIG. 9

solids fraction s and A is a point on the $V_S - T$ curve for a suspension of zero solids fraction (that is, individual particles). Then $AC = V_p$ and $BC = V_S$ so that

$$AB = AC - BC = V_p - V_S = V_p \left(1 - f s^{2/3}\right) = V_p f s^{2/3} = V_D \dots (10)$$

If, now, at least two $V_S - T$ curves are obtained by experiment, the values of f and V_p at various temperatures may be calculated from Eq. 6 and $AC = V_p$ scaled off at the corresponding temperature to give the curve for $s = 0$.

By using selected values of s at a fixed temperature, $V_p f s^{2/3} = AB$ may be calculated and scaled off and a point on each s curve established, and the s scale for that (or similarly, any other) temperature may be marked as shown on Figs. 3 to 8, and used to check the consistency of the results. If sufficient s scales are constructed, curves may be drawn for any desired values of s .

It will be noted that the temperature axis of Figs. 3 to 8 corresponds to the concentration $s = f - 1.5 = 0.216$ and that, for any given concentration, the velocity ratio, V_S/V_p is independent of temperature.

It should also be noted, however, that above a solids fraction of about 0.16 to 0.17, the s scale is no longer valid.

Examination with a magnifying glass of a number of suspensions of varying concentration indicates that the explanation of this is as follows:

At low values of the solids fraction, the particles are uniformly but widely spaced, and their settling is "hindered" in the sense previously defined, only by the proximity of their neighbors; the "hindered" settling law (Eq. 6) is valid.

As the concentration increases, the space initially occupied by the suspension becomes congested with particles, until at a solids fraction of 0.16 to 0.17, many particles may be observed to be initially adhering to one or more of their neighbors, so that they resist settling more effectively. Here and there, groups of irregularly shaped particles collapse and coalesce into one particle, with

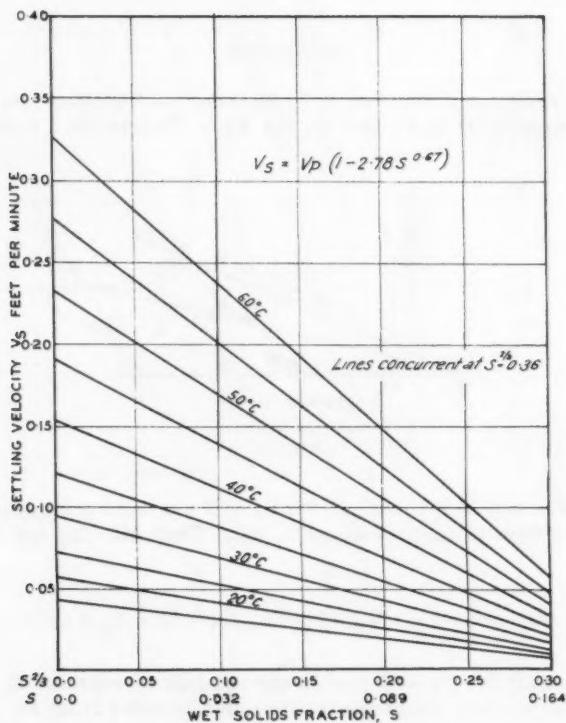


FIG. 10.—SETTLING VELOCITY AS A FUNCTION OF CONCENTRATION FOR FRESH ALUM SLURRY AT VARIOUS TEMPERATURES.

the same volume but a smaller horizontal cross section, and such a particle then settles more rapidly until impeded by another group. In other words, compaction as well as "hindered" settling is occurring, and the settling law is no longer valid.

Settling Velocity as a Function of Concentration.—Fig. 10 is a series of settling velocity-concentration curves at various temperatures, constructed from Fig. 3, with the settling velocity of the suspension plotted as ordinate, and the

two-thirds power of the solids fraction as abscissa. Similar figures* may be constructed from Figs. 4 to 8.

Each isothermal line is straight in accordance with the relation given by Eq. 6. All are concurrent at the point on the concentration axis where $S^{2/3} = 1/f = 0.36$, that is $s = 0.216$.

The intersection of each isothermal line with the settling velocity axis is determined from the $s = 0$ curve of Fig. 3.

In Fig. 10 the isothermal lines are terminated at $s = 0.164$, the approximate limiting value above which Eq. 6 is no longer valid.

The tests show, as in Fig. 2, that the settling velocity-concentration curves flatten abruptly soon after this value.

Value of the Constant f.—In the derivation of Eq. 6, it was stated that f was a constant dependent on particle shape. It might therefore be expected a priori that f would be independent of temperature.

When $V_S = 0$, $s = f - 1.5$; hence if f is independent of temperature, the settling velocity-concentration graphs for all temperatures will be concurrent on the concentration axis at this value of s . This was found to be so.

In practically every test made, with either alum or lime floc, the intersection was at $s^{2/3} = 0.36$, whence $f = 2.78$. This value of f was independent not only of the temperature, but of the kind of floc and the proportion of heavy particles in it. On the other hand, as would be expected, the value of V_p varied with each of these factors.

The theoretical discussion stated that the factor f was a constant depending on particle shape, and it is therefore necessary to point out that all samples were prepared in the same apparatus, and under the same conditions, except that the upflow velocity, and to some degree, the temperature, varied. On the other hand, the floc was completely broken up by shaking before each test.

Settling Velocity of the Individual Particles of a Suspension.—When $s = 0$, $V_p = V_S$ from Eq. 6. Hence the $s = 0$ curves of Figs. 3 to 8 give the value of V_p for various kinds of hydroxide suspensions, for varying temperature. The settling velocity of individual particles which do not necessarily conform to Stokes' Law may thus be determined from the settling characteristics of a suspension of the particles.

Settling Characteristics of Suspensions.—With a knowledge of the value of the constant f and a curve for $s = 0$ obtained as shown in Figs. 3 to 8, the settling characteristics of a given suspension at all ordinary temperatures are known.

The information given in these figures may be summarized as shown in Figs. 11 and 12 in which the $s = 0$ curves for various kinds of alum and lime suspensions are reproduced. In each case, for these suspensions, $f = 2.78$.

Compaction.—It has already been noted that at the end of the constant rate settling period (Fig. 1), a suspension of plastic particles such as hydroxide floc suffers an abrupt change in the rate of fall of its top (C, Fig. 1). Thereafter, the top continues to fall for some time, but at a gradually decreasing rate (CD, Fig. 1), and finally comes to rest.

During the constant rate period, all the particles fall more or less at the same velocity, that is, the suspension falls as a unit, and it would continue to

* "The Behavior of Suspensions," by A. W. Bond, Civil Engineering Transactions, Institution of Engrs., Australia, Vol. CEI, No. 1, March, 1959, pp. 1-17.

do so but for the interposition of the bottom. When the particles reach the bottom, or those previously deposited, they pack together, as closely as their structure will permit, in the same way as rigid particles do. The end point of the constant rate settling period (C) when all the particles have packed together will be referred to as the "packed" point. From that point on, they no longer resemble rigid particles.

Contraction of the length occupied by the particles still continues. This is, however, no longer due to the upper ones falling and packing on the bottom. Instead, the whole mass contracts more or less uniformly throughout its length, that is, the process is one of compaction, not settling. Compaction continues for some days; it is, however, within 2% or 3% completion within 24 hr.

Examination with a magnifying glass shows that, at the packed point, the large flocculent particles temporarily retain their shape, and pack together

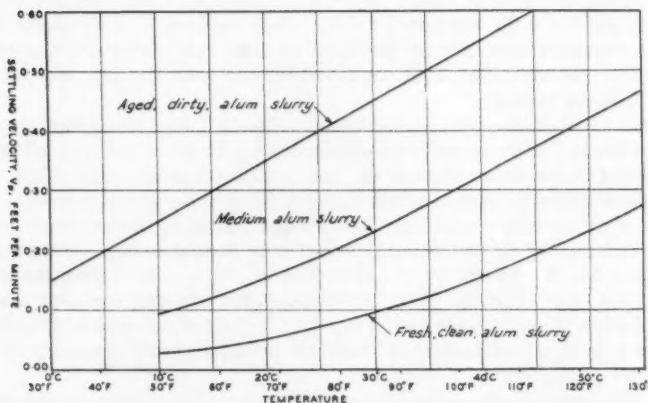


FIG. 11.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE OF THE INDIVIDUAL PARTICLES OF ALUM SLURRY FOR $f = 2.78$.

with a coarse, open texture. Up to this point they have behaved, although plastic, in the same manner as rigid particles. Thereafter, however, their structure changes under the influence of gravity; the particles, being plastic, collapse and they slump slowly together and fill the interstitial spaces, and the liquid there or entrapped in the particles is slowly expelled. The texture of the mass becomes finer and smoother until, after the lapse of some hours, it appears to be continuous.

The Packed Solids Fraction.—It was observed that at the packed point the solids occupied a volume of about three and one third times the final compacted volume, for a wide range of the initial solids fraction. Hence the solids fraction at the packed point, which will be referred to as the packed solids fraction, is about 0.30 for these flocs. The packed solids fraction is independent of s , the initial solids fraction.

The packed solids fraction is a parameter, not a constant, even when the settling test is repeated on the same sample. The coagulated particles are of many shapes and sizes, and pack together at random. There is therefore no reason to expect that the same weight of particles will pack into exactly the same volume each time. Further, the wider the variation in the "grading" of particles, the greater is the weight of suspended solids which will pack into a given volume, and hence the greater the packed solids fraction.

When the initial solids fraction is less than about 0.08, the suspensions coagulate into relatively few large and many small particles, and the packed solids fraction is greater than 0.30. A reduction in temperature (below 45°F.) has the same effect.

It has already been noted that true "hindered" settling, in the sense defined, occurs only in floc suspensions with an initial solids fraction less than about

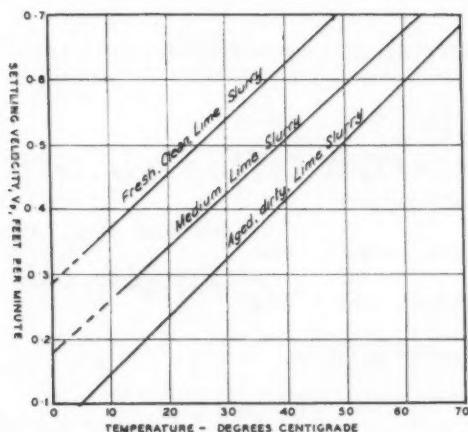


FIG. 12.—SETTLING VELOCITY AS A FUNCTION OF TEMPERATURE OF THE INDIVIDUAL PARTICLES OF LIME SLURRY FOR $f = 2.78$.

0.16 or 0.17. At higher initial concentrations, the particles are so densely packed initially that they are in loose contact with their neighbors and afford actual physical support to each other. Separate particles collapse and coalesce, and it is apparent that compaction as well as hindered settling is occurring.

It appears reasonable to conclude from what has been observed of the packed solids fraction, that when the initial solids fraction is 0.30 or more, "hindered" settling no longer occurs, but that the settling of the top of the suspension is entirely due to compaction.

Volume of Concentration Chamber.—The knowledge that suspensions of floc settle within a matter of minutes to the packed solids fraction, the value of which is known, and that thereafter compaction is very slow, is of value in the design of concentration chambers built into sedimentation basins. In such locations they are expensive, and the maximum economy will be secured if they

are designed to retain the settling suspension only long enough to enable it to reach the packed solids fraction, the rest of the compaction being carried out in cheaper external chambers. If rapid compaction is desired, broad shallow chambers are necessary.

PRECIPITATION OF SOLIDS

Rate of Precipitation.—Let w be the weight in pounds per cubic foot of the concentrated wet solids of which the solids fraction is unity. Then the weight in pounds of wet settled solids in 1 cu ft of suspension with a solids fraction s is $w s$.

Let p be the weight in pounds of wet solids of unit solids fraction settling through (or precipitating on) 1 sq ft in 1 min, and let V_g be measured in feet per minute. Then

and, from Eq. 6,

$$p = w s V_p (1 - f s^{2/3}) = w V_p (s - f s^{5/3}) \dots \dots \dots (12)$$

Differentiating,

$$\frac{dp}{ds} = w V_p \left(1 - \frac{5}{3} f s^{2/3} \right) \dots \dots \dots \quad (13)$$

For maximum p, $dp/ds = 0$, that is,

or

Substituting this value of s into Eq. 12,

$$p_{\max} = w V_p \left(\frac{3}{5f} \right)^{1.5} \left\{ 1 - f \left(\frac{3}{5f} \right) \right\} = 0.186 \frac{w V_p}{f^{1.5}} \dots \dots \dots (16)$$

The settling velocity V_R of a suspension precipitating at the maximum rate (pounds per square foot per minute) is, from Eq. 11, and substituting the value of s :

Thus the rate of precipitation of the solids in a suspension depends on the shape and free settling velocity of the individual particles of the suspension and its concentration and density, and there is a value of the concentration at which the rate of precipitation is a maximum.

The value of the parameters must be found by experiment. Their values at 15°C. for the floc produced in the Bacchus Marsh experiments are given in Table 3.

Slurry Withdrawal.—The withdrawal of solids precipitating on the bottom of a concentrator imparts a downward velocity to the suspension which increases the rate of precipitation. Consider the special case in which the solids are withdrawn continuously at the packed solids fraction, as fast as they pack. Let the rate of withdrawal (or precipitation) be p_1 pounds of wet solids at unit solids fraction per square foot per minute. Then p_1/w cubic feet of wet solids fraction per square foot per minute are withdrawn.

TABLE 3.—VALUE OF PARAMETERS—SETTLING

	Alum 1st run Fresh	Alum 2nd run Medium	Alum 3rd run Aged	Lime 1st run Fresh	Lime 3rd run Aged
Proportion of sediment	Low	Medium	High	Low	Low
Dry weight of solids, lb./cu. ft. of wet settled slurry ($s = 1.0$)	4.61	3.68	2.97	7.56	6.33
w - weight of wet settled slurry ($s = 1.0$), lb./cu. ft.	64.90	64.32	63.92	64.14	64.77
f	2.78	2.78	2.78	2.78	2.78
V_p - feet per minute at 15°C.	0.043	0.122	0.300	0.425	0.205
s for p_{max} .	0.1004	0.1004	0.1004	0.1004	0.1004
p_{max} - lb./sq. ft./min. of wet settled slurry ($s = 1.0$) at 15°C.	0.112	0.315	0.768	0.109	0.533

(The above values of V_p and p_{max} , will, of course, vary with temperature, according to the change in V_p as shown in Figs. 11 and 12.)

As the packed solids fraction s_p is much less than unity, a relatively large volume of water must be withdrawn with the solids. The rate of withdrawal of water and solids will be $p_1/(w s_p)$ cubic feet per square foot per minute, and the downward velocity due to withdrawal will be $p_1/(w s_p)$ feet per minute. Hence

$$p_1 = w s \left(V_S + \frac{p_1}{w s_p} \right) \dots \dots \dots \quad (18)$$

That is

$$p_1 = \frac{w s V_p (1 - f s^{2/3})}{1 - \frac{s}{s_p}} \dots \dots \dots \quad (19)$$

Area of Concentration Chamber.—The rate of formation of slurry in any water treatment process can be estimated from the throughput of raw water and the rate at which it is to be dosed. Slurry will be precipitated at the same rate as it is formed. If the rate of slurry formation is high, then it should be withdrawn at the same rate, in order to maintain the top of the slurry pool at a constant level. Hence, from the rate of formation of slurry and the unit rate of withdrawal as calculated above, the top area required for the concentrator can be estimated.

SUSPENSIONS IN UPFLOW

Upward Velocity and Concentration.—It is obvious that the velocity of settlement of individual particles on the one hand and of aggregations of particles, that is, suspensions, on the other, in upward flowing water is exactly the same, relative to the water, as in still water. To determine the velocity of settlement relative to the container but neglecting the drag of the walls, it is necessary to take into account the nominal velocity, V , of upflow, that is, the upflow velocity through the container when no particles are present.

The relation between the nominal upflow velocity V , the settling velocity of individual particles v_p , and the concentration s of a stationary suspension is deduced in the same way as before, to lead to

$$V = v_p \left(1 - f s^{2/3} \right) \dots \dots \dots \quad (20)$$

Transposing,

$$s = \left(\frac{1}{f} \right)^{1.5} \left(1 - \frac{V}{v_p} \right)^{1.5} = a \left(1 - \frac{V}{v_p} \right)^{1.5} \dots \dots \quad (21)$$

where $a = 1/f^{1.5}$ is a constant depending on the shape of the particles.

Eq. 13 gives the concentration which will be obtained in a stationary suspension, whose particles have a particular shape and settling velocity, for any given nominal upflow velocity.

A Model Expanding Upflow Zone.—A model expanding upflow zone was constructed to enable the behavior of a slurry pool to be studied. A line drawing of the apparatus is given in Fig. 13, and a photograph in Fig. 14.

Referring to Fig. 13, DE is a timber frame holding two rectangular plate glass sheets 3 in. apart. The expanding upflow zone, ABC, is formed by timber partitions between the glass sheets. Water containing floc particles is introduced at F, flows down the passage FC, and then upwards through the upflow zone.

Under suitable velocity conditions, a dense slurry pool of floc particles is suspended in the upflow zone up to the level AB, any surplus slurry overflowing the slurry weir at A and falling into the compartment AG, whence it may be withdrawn as desired.

The slurry weir was devised to fix the level of the top of the suspension, otherwise the latter would rise to a level determined by the amount of floc supplied to it, and the velocity at its top could not be controlled as desired.

The supernatant liquor overflows to waste at D.

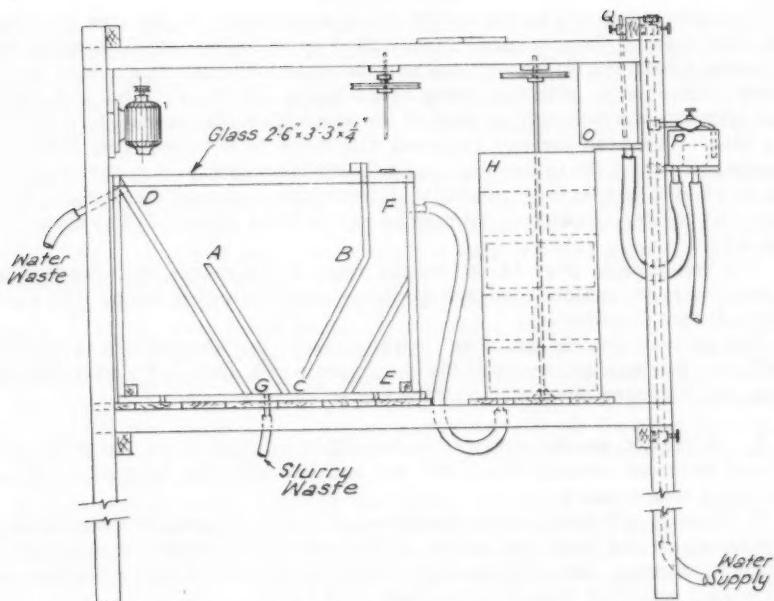


FIG. 13

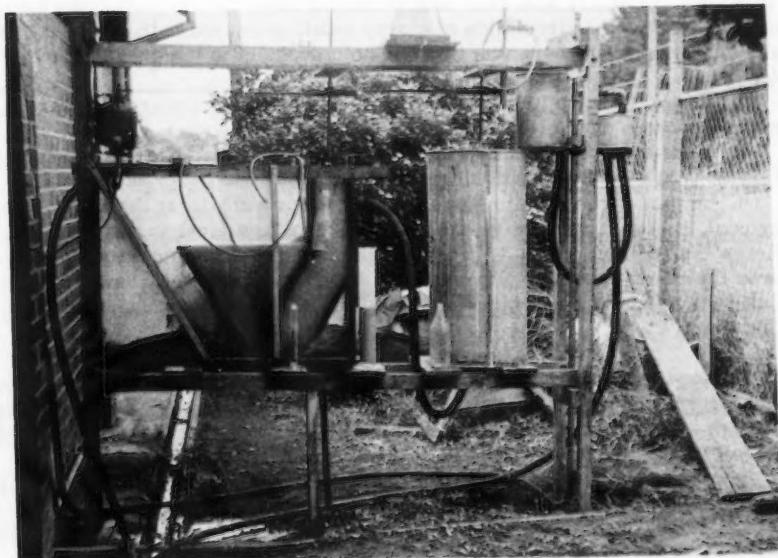


FIG. 14.—MODEL UPFLOW BASIN.

The upflow velocity at the top AB of the slurry pool is adjusted by varying the rate of flow. This, in turn, is controlled by an orifice box O, supplied from a constant head box P, whose level may be varied at will. The orifice box has three orifices at O, with diameters respectively 1/8 in., 3/16 in. and 1/4 in., one or more of which may be used at the same time, discharging into the mixing tank. The head for any required discharge is obtained from calibration charts and set on the measuring gauge Q, and the water level in the orifice box set at the desired level by raising or lowering the constant head box. In this way, the upflow velocity at AB may be varied from about 0.018 to about 1.3 ft per min.

The photograph, Fig. 14, shows the model in operation, with dense slurry suspended in the upflow zone and trickling over the slurry weir. The supernatant liquor is quite clear.

The Upflow Experiments.—As a preliminary, the apparatus was run until sufficient floc was accumulated for the experiments. During the trial and later runs, the following observations were made:

1. All the floc was dispersed when the upflow velocity at the top of the slurry pool exceeded about 0.30 to 0.40 ft per min, depending on the kind of floc and the water temperature.
2. Stirring at the entrance to the bottom of the slurry pool was necessary to prevent streaming near the bottom of the pool and deposition of slurry in the entrance passage. These effects were due to the size and shape of the entrance, and did not interfere with the upper part of the pool.
3. Slurry was precipitated on the sloping side walls at all levels and rolled down to the bottom of the upflow zone, where it was again picked up by the higher velocity there, lifted into suspension, and rose at a gradually decreasing velocity. No slurry was ever noticed falling down the vertical glass walls. A definite controlled circulation of slurry was thus caused in the lower portion of the slurry pool but there was little or no movement in the greater part, at the top.
4. At any given upflow velocity, the concentration of slurry appeared to be much the same over the whole volume of the slurry pool.
5. If the supply of particles is limited, then only a limited portion of the upflow zone will be filled with slurry.
6. Up to a certain limiting value of the upflow velocity at the top of the slurry pool, to be discussed later, the top of the pool was level and sharply defined. Hence the nominal upflow velocity and the interparticle velocity were uniform over the whole surface. The shape of the upflow zone would not contribute to this result, which must therefore be attributed to the dispersing effect of the floc itself.

Because of the circulation near the bottom of the pool, all samples were taken from about 1/2 in. below the top of the slurry pool, by siphoning off through a rubber tube, and the concentration was varied by altering the upflow velocity.

In order to define the characteristics of a suspension in an upflow, it is necessary to establish by experiment that Eq. 21 correctly represents the observed facts, to determine the value of a and a curve for V_p at all ordinary temperatures, for each kind of floc.

A series of tests was run with the water dosed with alum or lime, the upflow velocities being selected so that the shape of the velocity-concentration

curve could be determined. Half of each series was run with increasing and half with decreasing velocity. Each increase of velocity caused the slurry to expand and discharge over the slurry weir into the collecting chamber. Each decrease caused it to contract, and more slurry had to be added.

The same slurries were used later for the settling tests described previously.

Concentration as a Function of Upflow Velocity.—The results of the upflow tests were plotted with the upflow velocity at the top of the slurry pool as ordinate, and the two-thirds power of the solids fraction at the same level as abscissa. Plotted in this way, the points for each test fell approximately on a straight line, showing that Eq. 21 is valid.

An important feature of the velocity-concentration curves was the sudden change of slope, away from the straight portion, at a low value of the upflow velocity, in an exactly similar manner to the settling curves. The point at which this change occurs will be referred to as the "transition" point.

The value of a was found by producing the straight lines to the concentration axis. It was found that a was a parameter for all the alum flocs and a parameter of different value for all the lime flocs, at the temperatures within the limited range available.

It was impossible to measure the upflow velocity at which the concentration was zero. As this velocity was approached, the dispersing effect of the slurry was lost, and although little streaming was apparent, the small remaining amount of floc was unevenly distributed throughout the upflow zone and above it. Hence the values of the upflow velocity at which the concentration was zero were found by extrapolation.

As the velocity-concentration curves were used only to obtain the values of a and V_p in each case, they are not given here, but the results are shown plotted in another form.

Concentration as a Function of the Velocity Ratio.—Having determined the values of a and V_p for each test, the results were plotted, as shown in Figs. 15 and 16, for alum and lime flocs respectively, with the concentration as ordinate and the velocity ratio, V/V_p as abscissa. This device was adopted in an attempt to eliminate as far as possible the effect of variables which either could not be measured or could not be controlled.

On the same graphs the curve of Eq. 21 was plotted, using the appropriate value of a in each case. It will be seen that the plotted measurements quite consistently fall near the theoretical curve, and that, considering the nature of the material and the difficulty of measuring its concentration, their scatter is less than might be expected.

Effect of Temperature.—Referring to Figs. 3 to 8, and to the discussion of Fig. 9, it is seen that the velocity ratio, that is, the ratio of the settling velocity of a suspension in still water to that of its individual particles, depends only on the shape of the particles, as defined by the factor f and on the concentration. It is independent of the density of the particles and of the water temperature, at least in the range of 10° to 60° C.

It was not possible to determine the effect of temperature in the upflow experiments, but Figs. 15 and 16 show that the velocity ratio depends on the factor a and the concentration, and is independent of the floc density at a temperature of about 15° C.

At this temperature the velocity ratio in upflow was about the same, for each concentration, as for settling, after allowing for the difference in the value of the shape factor.

Since the settling of a suspension in still water and its suspension in upflow is the same phenomenon, it appears reasonable to assume that the velocity ratio in upflow is independent of temperature.

Disparity in Settling Velocities.—The settling velocity of individual particles depends on their shape and size, on the floc density, and on the temper-

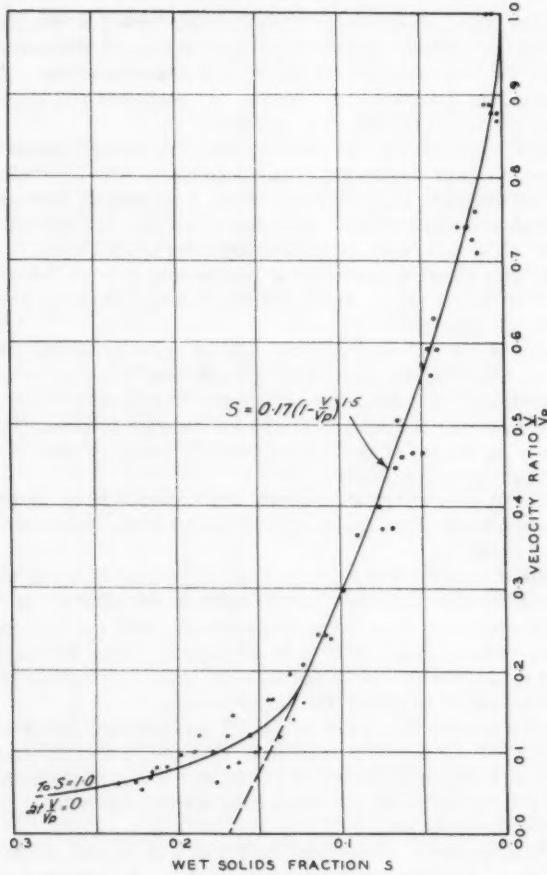


FIG. 15.—CONCENTRATION AS A FUNCTION OF THE VELOCITY RATIO FOR VARIOUS ALUM SLURRIES AT ABOUT 14° TO 16° C.

ture. Its value in still water is measured by that of the suspension and this is determined by the largest particles, which did not appear, especially at high temperatures, to vary greatly from those in an upflow.

After allowing for the different conditions of coagulation as affecting the shape and size of the particles, it might be expected that their settling velocity in still water and in upflow would be comparable. This was not the case. Only one value of the settling velocity of individual particles in upflow was available

for each kind of floc, all at about 15° C. Its value ranged from about 0.27 to 0.37 ft per min, whereas its value in still water for the same flocs at the same temperature, ranged from 0.04 to 0.42.

Discrepancy of Shape Factors.—From the derivation of the settling velocity-concentration relation in settling and in upflow, the relation between the shape

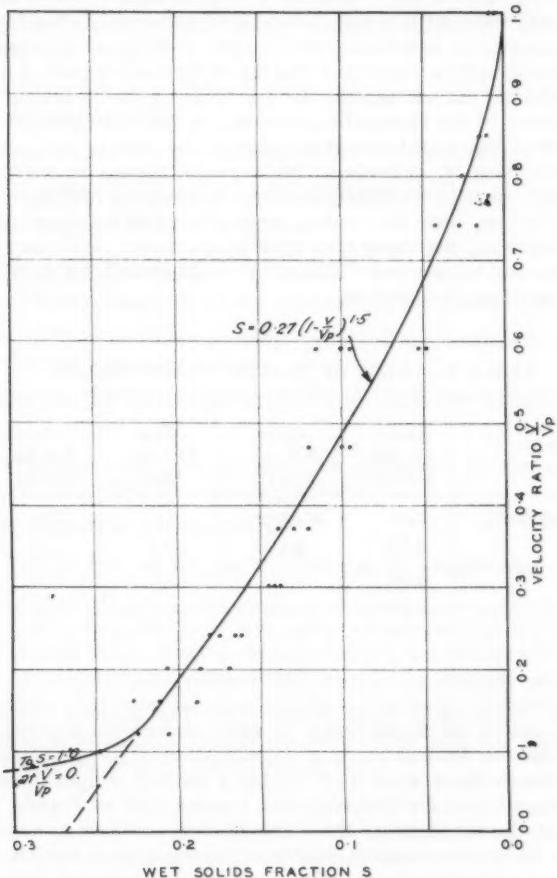


FIG. 16.—CONCENTRATION AS A FUNCTION OF THE VELOCITY RATIO FOR VARIOUS LIME AT ABOUT 14° TO 16° C.

factors a and f is $a = f^{-1.5}$. The experimental values of the two constants did not conform to this relation. The value of f in the settling experiments was the same for alum and lime flocs, namely 2.78, which corresponds with a value of 0.216 for a . In the upflow tests, the value of a for alum floc was 0.17 and for lime floc, 0.27 (Table 4).

Safe Limit of Upflow Velocity.—During the upflow tests, it was noted that the line of demarcation between the top of the slurry pool and the supernatant

liquor was very sharply defined for nominal upflow velocities at the top of the slurry pool up to about $0.5 V_p$. The slurry appeared dense and solid and the water above it was perfectly clear.

As the upflow velocity was increased above this value, the surface of the slurry pool became slightly blurred, and it was observed that some small particles were being lifted a short distance above the still definite, main surface. (It should be remembered that this discussion applies only when the level of the top of the suspension is arbitrarily controlled, as by a slurry weir.)

Up to a nominal upflow velocity at the top of the slurry pool of about $0.55 V_p$ or slightly higher, it did not appear that the lifting of particles would interfere with the efficiency of the separation process, taking into account the fact that the small scale of the model tended to magnify the effect.

At about this velocity, occasional boils would appear on the surface of the slurry pool, but would immediately subside, dispersing radially over the surface. Some of these, near the center, were attributed to slight streaming due to inefficient stirring, but these may have been caused, and others away from the center appeared to have been caused, by small pockets of smaller particles than average reaching the surface.

TABLE 4.—VALUE OF PARAMETERS IN UPFLOW

Parameter	Alum 1st run Fresh	Alum 2nd run Medium	Alum 3rd run Aged	Lime 1st run Fresh	Lime 3rd run Aged
Proportion of sediment <i>a</i>	Low 0.17	Medium 0.17	High 0.17	Low 0.27	Low 0.27
V_p	0.27	0.30	0.35	0.37	0.30

As the upflow velocity increased still further, the blurring of the surface became progressively more pronounced, until, at an upflow velocity of about $0.65 V_p$, particles of all sizes began to swirl up into the supernatant liquor, the suspension had no defined top, and the efficiency of separation was low.

The above observations were made within a limited temperature range ($14^\circ C$ to $16^\circ C$). From them, the following conclusions may be drawn:

At the top of the suspension, the removal of restriction in area due to the presence of the particles causes a sudden fall in the upward velocity of the water from the interparticle velocity to the relatively low nominal upflow velocity. The smaller particles which may be carried to the top by the interparticle velocity cannot be supported by low values of the nominal upflow velocity, and fail to rise above the surface, which is thus sharply defined.

As the nominal upflow velocity increases, the concentration decreases, the change in velocity at the surface is less, and a point is finally reached at which some of the smaller particles are carried beyond the general surface and are supported above it, partly at first by jet action, and later in greater concentration, by themselves restricting the area and creating their own interparticle velocity. Blurring commences, and increases as the nominal upflow velocity increases.

NOMENCLATURE

V = the nominal upflow velocity in an upflow zone in which no particles are present, relative to an external frame.

f, a = constants for each shape of particle.

V_S = the settling velocity of a suspension, usually in feet per minute, relative to an external frame.

V_P = the settling velocity of the individual particles of the suspension, relative to the same frame.

V_D = the interparticle velocity, relative to the same frame.

V_R = the settling velocity of a suspension precipitating at the maximum rate.

d = the mean dimension of the particles.

n = the number of particles in a short length l .

f_1, f_2, f are constants depending on the shape of the particles.

q = the rate of flow of water passing through a horizontal plane fixed relative to the settling suspension.

s = the concentration of a suspension, as measured by the wet solids fraction.

c = the concentration of a suspension, as measured by the weight of dry solids per unit volume of the suspension.

T = the temperature of a suspension.

w = the weight of wet solids per unit volume of a suspension of unit solids fraction.

p = the rate of precipitation of wet solids expressed as the weight of wet solids of unit solids fraction falling through unit horizontal area in unit time.

p_1 = the rate of withdrawal from a concentrator, of wet solids expressed as the weight of wet solids at unit solids fraction per unit horizontal area at the top of the concentrator, in unit time.

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SANITARY ENGINEERING ASPECTS OF NUCLEAR ENERGY^a

Progress Report of the Committee on the Sanitary Engineering Aspects of Nuclear Energy of the Sanitary Engineering Division

SYNOPSIS

The Committee has attempted to summarize and bring into focus a number of interrelated topics dealing with radioactivity. This paper reviews some of the advancements, current areas of interest, and future responsibilities of the sanitary engineering profession in the nuclear field.

INTRODUCTION

The atomic energy industry continues to have an impact on man and his surroundings. The potential environmental problems resulting from the use of ionizing radiation demand an individual insight and public exercise of social responsibility never before equalled.

The search for protection against dangerous radiation goes back to the turn of the century when the somatic effect of X-radiation was discovered. Prior to World War II, non-federal control of hazards and establishment of protective measures were mainly the user's responsibility. Increasing use of radioisotopes, development of nuclear energy for power, and a stratospheric inventory of thousands of curies of radioelements has precipitated a growing public awareness of the problem. The voluntary approach for controlling hazards and reducing unnecessary exposure is now being supplemented by more enlightened engineering practices and a general increase in regulatory control.

Note.—Discussion open until October 1, 1960. Separate Discussions should be submitted for the individual papers in this symposium. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SA 3, May, 1960.

^a Presented at the October 1959 ASCE Convention in Washington, D. C.

The sanitary engineer has a manifest duty to insure protection of the populace and conservation of the national resources. Fortunately, as a result of considerable foresight by engineers in the Atomic Energy Commission (AEC) and other agencies, problems such as radioactive waste disposal and ionizing radiation exposure are being attacked before their potential gravity becomes imminent. Never before has an industrial waste received so much considered attention. A recent publication attests to the amount of technical and public attention directed to the control of wastes in the atomic energy industry (1).¹

Programs for continuous environmental sampling and waste disposal research have been initiated at several levels of inquiry. The National Water Quality Network and the National Air Sampling Network of the United States Public Health Service (USPHS) are representative of the larger picture. Local studies, such as the current 125-station water sampling study in Texas, are undertaken primarily to determine the rate of radioactive discharge from nuclear installations, fall-out and natural radiation, and their combined effects on water use. These sampling programs are all directed toward the collection of basic environmental data.

The hazards of waste disposal and nuclear power production in general are in many respects directly related to the geographical location of the plant. This means that site selection for nuclear installation is also an important part of planning the nuclear environment.

Thus, it is essential to evaluate the contribution of each source of radioactivity to obtain the total environmental radiation hazard. In this manner control measures can be intelligently applied towards minimizing unnecessary radiation exposure to the whole population.

HEALTH PROBLEMS FROM A NATIONAL AND INTERNATIONAL POINT OF VIEW

World-wide concern over exposure to radiation has been prompted by expanding knowledge about hazards associated with nuclear energy releases and its effect on man and his environment. The impact of this concern on the various public health agencies is taking the form of demands for guidance and action. Older and more familiar sources of radiation such as medical and dental use of X-rays have not generated the same public interest despite the fact that they are a greater source of radiation exposure to the general population than the newer sources. Since some of the effects of radiation are cumulative, all sources of exposure should be assessed to determine their relative contribution to the total potential hazard. As the number of old and new sources continues to increase, the question of control of radiation exposure to the general population continues to be a growing health problem.

The advisability of one agency having the responsibility for both the encouragement of nuclear energy applications and establishing the exposure criteria for general populations involved has generated considerable interest. The National Advisory Committee on Radiation to the Surgeon General of the USPHS recognized the possible conflict of interest and recommended these responsibilities be assigned to separate agencies. Furthermore, the Committee recommended that the agency having the responsibility for health and safety be granted authority for broad planning in the field of radiation control. On August 14, 1959, the President issued an Executive Order establishing a Federal Radiation

¹ Numerals in parentheses, thus (1), refer to corresponding items in the Bibliography.

Council composed of the Secretaries of the Departments of Health, Education & Welfare, Defense, Labor, Commerce, and the Chairman of the Atomic Energy Commission. This Council has the responsibility of coordinating the efforts of government agencies in evaluating real and potential radiation hazards and informing the President.

The principal sources of radiation exposure are naturally occurring radioactivity found in the environment and man-made sources which include the medical and industrial use of radiation, fallout from weapons testing, and waste disposal from industrial and research operations.

Natural Background.—Natural background includes such genetic and somatic hazards as carbon-14, potassium-40, tritium, the daughters of thorium, neptunium, uranium, actinium, and cosmic rays. The significance of their role as health hazards has not been evaluated but investigations are underway—such as the study being conducted by New York State, and the USPHS studies on the Colorado Plateau and in Raymond, Maine. Another area not understood is the manner in which natural radioactivity has affected evolutionary processes.

Man has always lived in a radioactive environment. It is estimated that man receives a dose of 7 to 9 rems (roentgen equivalent man) in 70 yr from external radiation and internal exposure due to deposition in the body of naturally occurring radioelements.

Medical and Research Applications of Radiation.—The use of radiation in the healing arts is helping to bring about great advances in health and welfare of the population. Typical applications include the use of X-ray and fluoroscopic machines for diagnosis and therapy. Radioisotopes are used for such purposes as calculating blood circulation times, biochemical metabolism of specific elements required in nutrition, and irradiation of diseased tissues including cancerous growths in such organs as thyroids and brain tissues. Radiation is being used as a tool in medical research to gain understanding of basic cellular behavior such as mitosis as a result of exposure to ionizing radiation. It is estimated that the total medical use of all forms of ionizing radiation contributes a genetic dose of about 5 Roentgens to the average individual up to age 30: an amount similar to that received from natural background.

X-rays have been used since 1896 for diagnostic medical purposes while radium has been used for therapy since 1898. It is estimated that in the United States there are 125,000 X-ray units used in diagnosis and treatment by 65,000 dentists, 50,000 physicians and general practitioners, and 11,000 others practicing in the healing arts. Over 10,000 industrial, research and commercial radiographic and fluoroscopic units are used for various purposes. Other potential sources of X-ray exposures are testing and operation of high voltage electronic tubes, electron microscopes, X-ray diffraction units, and high voltage X-ray machines in research laboratories, universities, and other institutions. Machines such as cyclotrons, betatrons, synchrotrons and bevatrons can deliver high intensity radiation far in excess of levels heretofore imagined. At present, equipment capable of producing ionizing radiation is the largest source of man-induced whole population exposure.

Prior to 1946, the use of radioisotopes was essentially limited to a few installations having access to cyclotron-induced activities. The addition of pile-induced activities, fission products and special irradiations has changed the magnitude of the related protection problems. The summary of the distribution of radioisotopes within the United States prepared by the AEC indicated 4,424 users as of November 30, 1958. Shipments of radioisotopes between 1946 and 1958 totaled 117,594. Medical use of isotopes have predominated in the past but there is a phenomenal growth in the industrial use of isotopes.

Other Man-Made Sources of Radiation.—These sources include fallout from weapons testing, wastes from nuclear reactor operations, and industrial uses of radioisotopes. Exposure from these sources has been estimated to be less than a few per cent of the average genetic dose contributed by natural and medical uses of radiation.

1. Fallout.—The radioactive isotopes which cause environmental contamination following nuclear weapon tests are fission products finding their way to the surface. In considering the effects of most radiation exposure on population groups, we evaluate the benefits gained in terms of the risks involved. In this sense fallout is unique as compared to other sources such as the medical use of radiation, since the necessity or the benefits of testing weapons cannot be resolved scientifically. The purpose of nuclear weapons testing by the United States has been to help guarantee the safety of the Free World. Various concerned groups must help evaluate the total picture from the standpoint of their assigned responsibilities. In this manner the Federal Radiation Council informs the President.

Much of the apprehension in regard to fallout stems from its "invisible" characteristics. The five senses are not capable of detecting radiation.

2. Fission to Ground.—The observed pattern of fission product deposition appears to have a maximum peak in the latitude of about 40° N with minimal values in tropical regions and at the poles. A less clearly defined peak appears in the mid-southerly latitudes. Within any latitude, the deposition appears to be somewhat rainfall dependent, thus varying seasonally.

3. Ground to Food.—Much more world-wide information is required today in determining the mechanism of fission product uptake in different soils for different types of vegetation as to the relative role of foliar absorption, root-mat absorption, or absorption through the roots. Climatological, meteorological, geographical, and geological factors all contribute to variation in radionuclide concentration in food.

Since strontium-90 is deposited in human bone similarly to calcium, people obtaining their calcium requirements primarily from milk can take advantage of the added discrimination against strontium-90 which the cow's metabolism provides. For areas of the world where individuals are primarily on a rice diet, the intake of Sr 90 may be higher.

4. Food to Critical Organ.—Continuing emphasis may be expected on this link in the chain of world-wide monitoring programs. By means of radioisotopic analysis of diets and radioactivity of human bone and other organs it is possible to determine levels of long-lived radionuclide contamination in man. It should be realized that unresolved variations in the first two links cited above in the food chain are unimportant in determining the present and past degree of contamination in man since direct measurement of diet and critical organs automatically solve the myriad variables. Human samples can determine the levels of exposure that have occurred while food and dietary analyses can show the current exposures. The first two links are of importance, however, in predicting the extent of future contamination.

5. Critical Organ to Effect.—Considerable research is being accomplished in the area relating low dose rates to effect upon the world's population. Also, the feasibility of assumed permissible amounts of radioactivity for the general public is being investigated.

Although prudence demands the assumption that there is no threshold below which low dose rates are completely ineffective, there are some promising results with mice indicating dose rate dependence on genetic effects.

REGULATORY AGENCIES AND INDUSTRY RESPONSIBILITY

A cumulative summary (August, 1954, to July, 1958) of state activities in atomic energy prepared by the Atomic Industrial Forum (2) shows seven states with a comprehensive Radiation Protection Code, fourteen requiring registration of sources, and thirty states having established advisory or study groups. Six states report that major action, such as code, law, or registration is pending. This growing awareness on the part of non-Federal governmental agencies is primarily directed toward regulatory control of all sources of ionizing radiation. Different courses of action have been followed including (1) registration of source, (2) standards for occupation exposure, and (3) standards for environmental discharges or a combination of these three forms.

The variety of radiation sources presents a multifaceted danger which can be controlled not solely by regulation, but through a concurrent program of education, inspection, and enforcement. Orderly development of controls and full explanation to the public can prevent most of the emotional impact that may result.

The Model State Protection Act of the American Public Health Association, and Handbook 61 (3,4), "Regulation of Radiation Exposure by Legislative Means," published by the National Bureau of Standards, are excellent guides for the development of a radiation protection act. These suggested regulations, covering all sources of radiation, do not attempt to resolve all possible jurisdictional problems which might develop between federal, state, and municipal authorities.

Essential components of any radiation inspection program include:

1. Establishment of program objectives and operating procedures.
2. Recruitment and training of personnel.
3. Registration of all radioactive sources.
4. Development of public and professional support.
5. Evaluation of the whole program.

The general cooperation of the AEC and the USPHS in the form of training grants and offering in-service-training courses can be supplemented by short courses at a state or local level. Cooperation of educational institutions has been excellent in this area. These types of cooperation help to achieve the decentralization desirable in a program of this type, thus providing an effective working relationship with the individual operators and local health agencies.

Radiation Equipment.—One may justifiably ask, "Is inspection necessary? What can be accomplished?" Operators of X-ray units show a keen desire to have equipment inspected and to correct any hazards. Needed improvements are usually undertaken conscientiously with the realization that any unnecessary exposure should be reduced consistent with good practice. Operators welcome assistance and guidance that can be provided by trained public health workers. Emphasis on education should be the rule rather than the exception.

Some common defects in the use of radiographic units used in diagnosis may include exposure to the primary beam if directed toward occupied areas, scatter radiation, absence of adequate filtration in tube housing to reduce entrance dose, multiple sources in the same room, equipment being operated from an unshielded position, and inadequate primary beam collimation.

Fluoroscopic units may result in unnecessary exposure to the operator or patient where the useful beam extends beyond the fluoroscopic screen, excess scatter radiation from the patient and undersurface of the table, high table top dose due to a short target table top distance or excessive MA. Other factors

to be considered are the use of dark adaption glasses prior to fluoroscopic examination, installation of integrating timers on older units, and utilization of protective aprons and gloves.

Primary and secondary radiation from therapy units usually operated at higher voltages and a greater work load, may result in needless exposure in occupied or controlled areas due to inadequate structural shielding. Other factors to be considered are the removal or failure of safety devices, electrical hazards, and building alteration.

A well-trained and equipped local health agency can provide a service to operators of radiation installations by developing a comprehensive inspection program.

Radioactive Isotopes and Naturally Occurring Radioelements.—Through the use or misuse of radium in previous years and the resultant exposure of workers, the body burden for many internal emitters has been determined from deposition of this radioelement in the bodies of radium workers.

Radium, used in the past in its refined state (usually as a sealed source), may create particular health problems. In the medical use of radium or radon, nurses, technicians, radiologists and others who are in the vicinity of the source are potentially exposed. Such exposure may be due to improper storage, preparation, application, sterilization, and transportation within the hospital or institution. Radium capsules which have ruptured may cause widespread contamination in hospitals or industrial installations resulting in direct exposure from ingestion or inhalation of the radioactive material. Radium can be purchased and used in the absence of state or local regulations, without formal application or special facilities.

Congress, under the provision of the Atomic Energy Act of 1946, granted the AEC statutory authority for establishing regulations applicable to hazards which might arise from the use of radioactive isotopes. Through the licensing and inspectional program of the AEC a commendable safety record has been achieved. Federal controls have been supplemented by the enactment of rules and regulations at state and local levels.

The addition of fission products and special irradiation has changed the magnitude of protection problems. Widespread laboratory, industrial, and research use of radioisotopes will continue. This involves protection of the scientist, technician, industrial worker, and the public. Severe internal radiation hazard is associated with those isotopes of long half-life, low elimination rates, and high uptake deposition in small organs or in bone. In promoting the safe use of radionuclides, an evaluation of potential hazards must include occupational and environmental hazards, external and internal exposure, acute or chronic.

With the increasing quantities of radioactive materials that are used in peacetime application by both AEC and non-AEC institutions, there has been a corresponding increase in the quantities of low-level waste which may represent a potential health hazard. Conventional disposal methods for residual amounts of radionuclides in paper wipes, rags, wraps, ashes, animal carcasses, and contaminated laboratory material cannot be used without consideration of the potential environmental hazards.

In medical diagnosis, the quantities are usually small and hazards readily controlled when proper precautions are followed. Therapeutic and research use of isotopes may present additional problems in the handling of material, patient, and wastes so as to avoid unnecessary exposure. For example, the handling of a cadaver containing residual amounts of radioactivity may be a ha-

zard to the pathologist or mortician coming in close proximity to the body. Occupational hazards are readily controllable during routine usage with reasonable supervision. An occasional accident, spill, overexposure or problem of air, water and soil contamination will occur, since no regulation, code, or law can conceivably cover all exigencies. Through sound program planning we can anticipate many of the present and future problems, thus controlling virtually all sources of man-made radiation through preventive action.

Radioactivity Sampling Networks.—The USPHS, AEC, and a number of states and municipalities have conducted various types of air and water investigations as related to radioactivity. The AEC, in its extensive plant and atmospheric studies, has kept meticulous records and maintained research in air contamination since the early days of the Manhattan Project. Much of the work has been reported (5). The data reported below are primarily those of the USPHS.

National Sampling Network.—In 1953 the USPHS, through its Robert A. Taft Sanitary Engineering Center at Cincinnati, initiated a survey of the particulate air pollution of urban and non-urban areas of the United States. A recent publication (6) presents results of the first 5 yr of operation of this national network. The primary objectives were to assemble basic data on the nature of the pollution of the air of the United States, to show trends with time, geographical variation, and the influence of other factors such as topography, climate, and population. Radioactivity is included among the many analyses performed.

The network at present includes approximately 185 urban and 51 non-urban stations in the 50 states, Puerto Rico, and the District of Columbia. The urban stations are sampled on an annual, biennial, or triennial basis, while the non-urban stations are all sampled on a yearly basis. In any one year there are approximately 115 urban and 51 non-urban stations sampled. The non-urban stations have been placed in the following geographic and land use categories: Atlantic, Gulf of Mexico, Appalachian, Great Lakes, Continental Divide, Pacific, forest, farmland, and desert or wasteland. These stations were selected so as to serve as control or check stations.

Stations in the states and territories are arranged in nine regional groups corresponding to the regional organization of the USPHS. They are as follows:

New England:	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Mid-Atlantic:	Delaware, New Jersey, New York, Pennsylvania
Mid-East:	District of Columbia, Kentucky, Maryland, North Carolina, Puerto Rico, Virginia, West Virginia
South-East:	Alabama, Florida, Georgia, Mississippi, South Carolina, Tennessee
Mid-West:	Illinois, Indiana, Michigan, Ohio, Wisconsin
Great Plains:	Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota
Gulf-South:	Arkansas, Louisiana, New Mexico, Oklahoma, Texas
Rocky Mountain:	Colorado, Idaho, Montana, Utah, Wyoming
Pacific Coast:	Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington

Tables 1 and 2 present a summary of radioactivity results at the urban stations by regions and at the non-urban stations for the period 1953-1957. These tables are taken directly from the Air Pollution Summary for 1953-1957 (6).

As may be seen, for example, the radioactivity of air particulates averaged 33.9 micromicrocuries per cu m for the Rocky Mountain area over the period 1942-1947, which was markedly higher than any other area. In another sense, 90% of the results for this area were equal to or less than 15.9 micromicrocuries per cu m, indicating that the higher average for the entire period resulted because of the infrequent occurrence of high results.

Table 2 indicates the radioactivity data for non-urban stations. As shown, the average for the United States over the period 1955-57 was 5.2 micromicrocuries per cu m, with 90% of the 412 results being less than or equal to 8.8 micromicrocuries per l.

TABLE 1.—RADIOACTIVITY—URBAN STATIONS—REGIONAL AND GRAND TOTALS

State or Region	Years	No. of Samples	(Micromicrocuries Per Cubic Meter) $\times 10^{-1}$											
			Min	Max	Avg	Frequency Distribution-Percent								
						10	20	30	40	50	60	70	80	90
New England Total	55, 57	279		588	33	3	7	10	12	14	18	26	37	69
Mid Atlantic Total	53, 57	611		930	31	1	4	7	9	12	16	21	30	53
Mid East Total	53, 57	406		826	26	2	4	6	9	13	17	22	30	48
South East Total	53, 57	445		2717	45	1	3	6	9	13	19	26	43	82
Mid West Total	53, 57	991		1179	27	1	2	4	7	10	15	20	28	47
Great Plains Total	53, 57	453		3240	44	1	3	6	10	13	17	24	37	82
Gulf South Total	53, 57	637		1931	49	2	3	6	9	13	17	25	37	77
Rocky Mtn. Total	53, 57	237		54350	339	3	6	11	15	20	29	41	67	159
Pacific Coast Total	53, 57	786		7319	43	1	1	3	4	8	11	16	25	41
Grand Total	53, 57	4845		54350	52	1	3	5	8	12	16	22	33	59

Interpretation of Table: In the New England area 50 per cent of the radioactivity readings were equal to or less than 1.4 micromicrocuries per cubic meter.

A paper soon to be released (7) presents a detailed summary of the results of radioactivity measurements for air particulates for the period 1953-1958.

National Radiation Surveillance Network.—The Division of Radiological Health of the USPHS operates a radiation surveillance network of 44 stations, 41 of which are maintained by state, territorial, or local health agencies. One of the objectives of this network is the routine collection of air samples throughout the nation for determination of airborne radioactivity. Samples are collected and assayed on a daily basis in contrast to the National Air Sampling Network which collects and assays samples on a longer term basis. The data from each of these two networks combined yield detailed information for the air of the United States, indicating both short and long term trends, both local and national.

Data from the National Radiation Surveillance Network are presently being listed on punch cards, and summaries will be available soon.

National Water Quality Network.—The USPHS National Water Quality Network was established under the provisions of the Federal Water Pollution Control Act of 1956. The overall objectives of this program are to provide: (1) long term information on changes in water quality at key points in river systems, (2) continuous information on the nature and extent of pollutants affecting water quality, and (3) data which will be useful in long-range planning of

TABLE 2.—RADIOACTIVITY—NON-URBAN STATIONS

Station Location	Site	Yrs.	No. of Samples	(Micromicrocuries per Cubic Meter) $\times 10^{-1}$												
				Min	Max	Avg	Frequency Distribution—Per cent									
				10	20	30	40	50	60	70	80	90				
Litchfield City, Conn.	1	55, 56	11		21	9	1	3	4	5	7	11	12	18	20	
Acadia Natl. Park, Me.	1	57	16	2	32	15	4	6	7	10	12	20	22	26	28	
Mt. Mansfield, Fst. Vt.	1	57	7	8	189	60	9	9	12	20	42	42	69	113	113	
Worcester City, Md.	1	57	24	5	374	35	5	8	9	14	17	20	25	33	54	
Cape Hatteras, NC.	1	57	8	10	55	19	12	13	13	14	14	15	18	18	20	
Shenandoah Park, Va.	1	57	25	8	654	73	12	14	18	22	26	36	48	62	186	
Holy River P-K, W.Va.	1	57	25	3	710	59	9	12	18	22	26	36	48	62	82	
Gulf Shores Park, Ala.	1	57	12	8	126	35	9	12	16	18	19	20	26	54	88	
Fla. Keys, Fla.	1	57	14	8	174	55	9	12	22	25	26	42	75	82	145	
Oatland Island, Ga.	1	57	16	4	54	22	6	7	11	12	18	26	30	38	42	
Jackson Cnty., Miss.	1	57	20	9	1129	135	11	13	15	18	20	23	26	54	391	
Ft. Donelson, Tenn.	1	57	16	9	353	73	10	11	20	22	26	48	54	69	186	
Sangamon Cnty., Ill.	1	57	13	13	87	26	13	15	20	21	23	23	24	25	42	
Huron Cnty., Mich.	1	57	30	5	226	36	7	9	10	12	16	19	26	54	69	
Perrys Mem., Ohio	1	57	8	5	64	22	6	10	10	11	12	15	20	20	54	
Ellis Cnty., Kansas	1	57	11	5	1316	159	6	9	23	26	54	62	69	79	88	
Cook City., Minn.	1	57	14	9	122	24	9	11	12	14	14	15	18	20	54	
Shannon Cnty., Mo.	1	57	18	8	239	47	12	15	16	19	26	31	42	54	105	
Thomas City., Nebr.	1	57	11	3	560	92	3	7	9	18	26	54	69	129	145	
Ward Cnty., N. D.	1	57	13	4	36	12	4	5	5	6	11	12	15	18	26	
Black Hills Fst., S. D.	1	57	5	15	730	164	15	15	20	20	30	30	33	33	823	
Yellowstone Park, Wyo.	1	57	2	20	100	60		20	20	20	20	20	20	113	113	
Pt. Woronzof, Alaska	1	56, 57	45		38	8	1	2	3	4	6	8	10	12	22	
Grand Canyon, Ariz.	1	57	26	7	830	134	14	17	23	30	39	88	129	186	391	
Waimea, Hawaii	1	57	22	2	86	18	3	4	6	7	9	16	18	33	42	
Grand Total			55, 57	412		1316	52	5	8	11	14	18	22	30	48	88

Interpretation of Table: At Litchfield County, Conn., 50 per cent of the radioactivity readings were equal to or less than 0.7 micromicrocuries per cubic meter.

water resources programs. The stations are located primarily on major waterways used for public water supply, and on interstate, coastal, and international boundary waters.

At the present time samples are collected at approximately 50 stations from which a wide variety of analyses are performed. The sampling at each station is on a continuing basis, with some samples being collected and analyzed week-

ly while others are on a monthly routine. The samples for radioactivity analysis are collected and analyzed on a weekly basis.

Gross alpha and beta measurements are made on both the suspended and dissolved solids in the raw surface water samples. The radioactivity of the dissolved solids provides a rough measurement of the radioactivity which can be expected to pass through water treatment plants and appear in the finished water, since most treatment processes will remove essentially all of the suspended activity but very little of the dissolved activity.

A recent publication (8) presents the annual compilation of data of the National Water Quality Network for the first year of operation ending September 30, 1958. A paper recently presented by L. R. Setter, et al, (9) summarizes in considerable detail the radioactivity data from the aforementioned annual compilation. Tables 3 and 4 are drawn from these two publications as examples of the extent and nature of results obtained thus far.

TABLE 3
Radioactivity of Surface Waters
Year Ending Sept. 30, 1958

Drainage Area	Average Beta Radioactivity micromicrocuries per liter		
	Dissolved	Suspended	Total
Great Lakes	8	3	11
N. Atlantic Coast	23	13	36
Savannah River	19	14	33
Tennessee River	36	19	55
Rio Grande River	41	48	89
Colorado River	25	9	34
Arkansas River	116	121	237
Columbia River	529	54	583
Snake River	20	18	38
Red River	28	55	83
Ohio River	22	23	45
Central Missouri	32	22	54
Lower Missouri	37	78	115
Central Mississippi	33	11	44
Lower Mississippi	26	42	68

The interpretation of data presented in Table 3 is self-evident. For example, surface waters of the Great Lakes area contained the lowest concentrations of beta radioactivity for the United States, while the Columbia River contained the greatest. The higher results for the Columbia River stations resulted from the discharge of short-lived wastes from Hanford.

Table 4 presents the results for the 1957-1958 water year as regards the distribution of dissolved beta radioactivity. Thus, from Table 4 it is seen that the Pacific Northwest Basin had the highest radioactivity as gross dissolved beta, again indicating the presence of short-lived radioactive wastes from Hanford. The Southwest-Lower Mississippi apparently contained the next highest concentrations of dissolved beta radioactivity on the whole.

In addition to these data, National Water Quality Network Samples are now being assayed routinely for strontium-90. Samples collected weekly are com-

posed on a quarterly basis and analyzed. The first set of 48 results for the United States, one result each for 48 stations, indicated a range of 0.0 to 4.7 micromicrocuries per liter of strontium-90 (10). This set was for the quarter ending March 31, 1959.

Other Investigations.—In addition to operation of the National Networks, the USPHS has been actively engaged in special studies involving the pollution of waters by radioactive wastes. Some of these are briefly described below. Other studies which have been carried out by the USPHS are described in a paper by Tsivoglou (11).

Uranium Refinery Studies.—The uranium ore refinery industry has expanded at a rapid rate in the past 10 yr. At the present time there are a total of

TABLE 4
Radioactivity of Surface Waters
Water Year Ending Sept. 30, 1958

Major Drainage Basins	Dissolved Beta Activity in $\mu\text{c/l}$. Frequency Distribution-Cumulative Per Cent								
	10	20	30	40	50	60	70	80	90
Northeast	1	4	7	10	13	15	18	20	27
North Atlantic	0	3	6	9	12	16	20	28	40
Southeast	3	6	9	12	14	16	19	22	29
Tennessee R.	3	10	16	23	32	39	46	55	122
Ohio R.	0	5	9	14	18	22	28	36	52
Upper Mississippi R.	2	9	16	22	27	33	39	48	66
Western Great Lakes	0	1	3	5	8	10	15	21	28
Missouri R.	7	14	20	24	28	33	39	46	61
SW-Lower Mississippi R.	5	13	19	26	34	43	54	70	114
Colorado R.	4	11	15	19	24	28	32	37	50
Western Gulf	5	13	17	23	33	39	47	62	99
Pacific Northwest	11	22	62	124	289	771	1253	1735	2217
U. S. Total:	2	8	13	18	24	30	38	51	103

Interpretation of Table: In the Northeast Basin 50 per cent of the radioactivity readings were equal to or less than 13 micromicrocuries per liter.

23 operating refineries in the western United States with a combined capacity of about 20,000 tons of ore per day. In the refineries uranium is extracted from the ores and concentrated, with the concentrate being sent to other nuclear installations for further processing.

In the waste discharges from these refineries radium is the most hazardous radioisotope present. Only the uranium is wanted and all the daughter elements such as radium, thorium, and others appear in the waste discharges. Most of the wastes from these refineries are retained in large tailings ponds or lagoons, but some of the wastes are discharged to nearby streams.

In 1955 at the request of several State Health Departments, the USPHS began a series of studies to evaluate the water pollution effects from the uranium refinery industry (12). Since 1957 the USPHS and the AEC, in a cooperative

effort, have been engaged in developing an industrial waste guide for this industry. Specific objectives include detailed analysis of the extraction process, characterization of the resulting wastes, evaluation of their water pollution and public health significance, and development of adequate and suitable waste control measures (13).

Animas River.—Under the provisions of the Federal Water Pollution Control Act of 1956, and at the request of the State of New Mexico, a conference was held in April of 1958 to assess the interstate pollution of the Animas due to waste discharges of an uranium ore refinery. At that time very little information was available regarding the extent and effects of pollution. On the basis of this conference it was agreed that a fact-finding survey would be carried out to measure the extent of radioactive, chemical, organic, and bacteriological pollution, and the effects of such pollution on existing legitimate uses of interstate waters (14).

The fact-finding survey was begun in July, 1958, and included a period of intensive survey of 2 months followed by limited routine sampling for an additional 10 months. With the cooperation of the industry, a brief industrial waste survey of the uranium mill was also performed. On the basis of the initial 2-month study a report was issued (15). It indicated the presence of excessive radioactive and chemical pollution from the uranium plant, with resulting interference with downstream water uses. Accordingly, at a second session of the conference held in June, 1959, the facts were presented and remedial measures were agreed upon, with specified time for completion. Since that time the industry has proceeded to institute the remedial measures and abate pollution.

Shippingport, Knolls Atomic Power Laboratory, and Savannah River Project.—The radiological Health Division of the USPHS, through its Radiological Health Research Section at the Sanitary Engineering Center, is conducting cooperative studies with the AEC on the movement of specific radionuclides discharged from the above-mentioned installations.

State and Local Radioactivity Monitoring Activities.—Many of the states and a number of local communities have also engaged in water and/or air monitoring for radioactivity at selected locations. These activities range from the determination of gross radioactivity in one or another kind of sample to assay for specific radioelements in a variety of samples. Much of the information obtained by these agencies is also transmitted to the several USPHS Networks for compilation into national averages and summaries.

LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTES

Intermediate and low level radioactive wastes may originate at reactor fuel processing plants, at the site of power reactors, in various industries employing radioactive sources, and at medical and research installations. High level wastes are produced at a relatively few central locations and are handled with great care by personnel highly trained in dealing with radioactive materials, whereas low and intermediate level wastes occur with all users of radioisotopes at thousands of locations and generally within populated areas. These wastes range in radioactivity concentrations from perhaps a few hundred millicuries per gallon down to the same order of magnitude as the maximum permissible levels for drinking water. Although the aggregate annual production of intermediate and low level wastes represents a very small fraction of the total activity of radioactive wastes, it can be argued that in terms of environmental

hazard these smaller quantities of radioactivity may, in fact, be more significant than the highly concentrated materials.

An examination of a recent compilation of data on radioactive wastes from power reactors and their processing plants by E. D. Arnold (17) and an annotated bibliography by H. E. Voress, T. F. Davis, and T. N. Hubbard (18) provide little insight into either the current or future nature of the low and intermediate level waste problem. Arnold (17), after examining a group of chemical processes for handling power reactor fuel elements, concludes that the intermediate-level wastes from such operations have a volume of about ten per cent that of the high-level wastes and activities 10^3 to 10^4 below the high-level wastes. No mention is made of the low-level flow from such installations. However, in reviewing the various methods of concentrating and reprocessing stored high-level wastes, that is, methods used to reclaim costly tank storage volume, it becomes apparent that ultimately much of this volume will fall into the intermediate or low level category and industry will look to the plant environment for dilution capacity. As a typical example, the condensate from self-boiling, high level wastes must be treated as an intermediate-level effluent. As a further example, studies have been made with the objective of removing long-lived strontium-90 and cesium-137 from high level wastes and converting them into a solid, non-leachable package. In this instance the residual liquid would constitute an intermediate-level waste as it would most certainly contain sufficient strontium and cesium, as well as other fission products, to preclude its discharge to any but the largest water course.

Perhaps the major reason for the absence of data on low and intermediate level wastes is the fact that the isolated locations and unique geology of the present fuel processing centers have made it possible to discharge these wastes into the earth and nearby rivers. Such measures represent economic and reasonably safe solutions at these sites at the present. However, it is doubtful whether such practices will be applicable to future sites and they certainly will require careful examination in an expanding nuclear economy. The facilities for handling process wastes at the Oak Ridge National Laboratory, as recently described by K. E. Cowser and R. J. Morton (19), are typical of measures that will be required to alleviate the contamination of surface waters in a period when standards of protection are becoming more stringent and the quantities of radioactivity present from low and intermediate level wastes in streams continue to rise.

Capacity of the Environment to Receive Radioactive Waste.—The permissible concentration of radio-contaminants in a receiving water is an essential piece of information to the designer of a nuclear power station or chemical processing plant and the associated waste storage, treatment and dispersal facilities. Since wastes are often produced at varying rates, it is also necessary to have specified allowable deviations from the average permissible concentrations in order that hold-up facilities may be properly designed. Although the National Committee on Radiation has recommended maximum permissible levels of various radioisotopes in drinking water for large population groups, these recommendations or some fraction of the values cited have not been widely accepted as directly applicable to the receiving water.

There are several reasons for this conservatism and the reluctance of local regulatory agencies to accept drinking water standards at face value. Public concern is probably the most influential factor. The belief by an increasing number of biophysicists (20) that a linear relation exists between life span shortening, leukemia incidence, etc., and radiation dose even at doses less than

one roentgen, has led to the continued reiteration of the long-standing philosophy that "radiation exposures from whatever sources should be as low as practical" (21). Since the term "practical" has a galaxy of interpretations, it is little wonder that health agencies feel compelled to impose large factors of safety in approving radioactive waste discharges.

Perhaps typical of current thinking is Industrial Wastes Permit No. 1832 of the Pennsylvania Department of Health (22). In setting discharge requirements for the Shippingport Power Station, employing a pressurized water type of nuclear reactor, the permit specified that the wastes shall at no time carry more radioactivity, exclusive of tritium, than 10^{-8} microcuries per ml in excess of that in the plant intake water. The value 10^{-8} corresponds to the life-time permissible level in drinking water for radioactivity of unknown mixtures. It seems that the practice of allowing some dilution in the receiving water is not permissible in this instance.

Another factor that should make for conservatism in the direct adaptation of drinking water standards to waste discharge requirements is their lack of applicability. For example, water containing the long-lived cesium-137 is very significantly less hazardous to the individual water consumer than to the agricultural worker employing the same water for irrigation. A great affinity for cesium by soils and the gamma radiation produced in decay are responsible for this perhaps unexpected relation. The adsorption of various radionuclides by soils and their concentration in plants and at various points in the food chains of aquatic organisms serve to complicate the establishment of water quality criteria. These conditions, coupled with both the uncertainties of low-radioisotopes concentrated in the human body and the effects of their radiation on life processes, dictate that we proceed slowly in establishing standards. However, for the benefits of nuclear energy to be fully and quickly realized it is essential that an underlying risk-benefit philosophy be established upon which standards of permissible environmental contamination may be based. Equating economic benefit to biological damage demands arbitration between industry and health agencies.

Methods of Treatment.—The treatment of low and intermediate level wastes is intended to concentrate the contaminating radioactivity in economically and safely stored packages and to produce an effluent compatible with the environment. The methods available include chemical precipitation, ion exchange, earth disposal, physical concentration such as evaporation or freezing, and biological systems.

Ion exchange with synthetic resins is finding greatest application to the decontamination of primary coolants of reactors and to water employed in reactor shielding. In these instances the waters are demineralized before being introduced into the neutron flux and consequently the exchanges exhibit a very great capacity on a liquid volume per unit resin basis. Since the treatment effluent is returned to the coolant or water shield system, highly efficient decontamination is neither required nor achieved. The radionuclides originate with the neutron activation of water impurities and corrosion products. Many of the nuclides appear to be present as radiocolloids and are not predictably removable by ion exchange systems.

H. Levin, W. J. Diamond, and B. J. Brown (23) reported that the removal of minute concentrations of radionuclides by resins may be markedly influenced by ionic strength. Thus, if isotopes such as strontium-90 are associated with high rather than low concentrations of calcium and sodium, it may be possible to obtain greater decontamination factors for these isotopes.

E. Glueckauf and P. J. Roberts (24) have reported on a method of removing radiocations involving the passage of waste through an anion resin in which the exchange sites were occupied by anions forming insoluble salts with the cations to be removed. The beds were regenerated by washing with acid or complexing agents.

Chemical precipitation is useful in the economic treatment of large volumes of waste where a high decontamination factor is not required. This may be accomplished either by carrier precipitation of the radionuclides or by absorption on a preformed floc.

Phosphate coagulation is used at Harwell, England, for treatment prior to discharge to the Thames River, and this practice is followed at many sites in Europe (25). Lime is added to raise the pH to 9.5 or 10, then 50 to 100 ppm of phosphate ion is added to form a calcium phosphate floc. Secondary treatment is provided the effluent of the upflow (sludge blanket) separator by passing it through a vermiculite filter for removal of radioactive cations by ion exchange. Volume reduction depends more on the amount of coagulant added than on the salt content of the original waste. Alum coagulation of liquid wastes at Windscale provides a decontamination factor of 5 to 10.

Cowser and Morton (19) report that the chemical treatment plant at Oak Ridge, which was designed for the treatment of 0.5 to 0.7 mgd of low-level waste, can provide 80% to 90% removal of strontium and the total rare earths by the lime soda ash softening process, using an excess of the chemicals. In addition, clay is employed for the adsorption of cesium so that it is largely removed also. This is accomplished at a total cost of \$0.18 per 1,000 gal of waste.

K. G. Seedhouse (26) reports similar results in precipitating hardness with tri-sodium phosphate and ferric chloride. This process removed 94% of the gross beta-gamma activity in 12,000 gal of waste put through a pilot plant. Here, too, the cesium was removed by adsorption on clay.

Physical concentration of radioactive salt in liquid wastes includes evaporation and freezing. Evaporation was one of the first concentration procedures employed on an experimental basis, because the process is more predictable than any other discussed herein. Unfortunately, the high cost of distillation makes this method too expensive except for wastes of high salt content, since costs generally exceed \$0.05 per gal.

Recently developed stills are capable of concentrating the waste to 70% solids. The decontamination factor is usually in the range of 10^3 to 10^4 , but by providing a 4 ft to 6 ft Fiberglass vapor filter to prevent carry-over of salts and by adjusting the pH at 7.5 to 8.5, preventing volatilization of ruthenium and iodine, decontamination factors of 10^6 are possible (27).

Evaporation is used for some of the wastes at Brookhaven and Shippingport, and as secondary treatment following phosphate coagulation in the case of some higher level wastes at Harwell. The concentration is generally mixed with concrete for disposal at sea.

Freezing has been used as a physical means of dewatering sludge from phosphate coagulation treatment units at Harwell (25). The sludge is frozen, thawed, and immediately dewatered. The concentrated sludges are then drummed for disposal at sea.

Ultimate Disposal.—One object of treatment of low and intermediate level wastes is to produce an effluent compatible with the environment. Except where earth disposal is used to provide concentration as well as ultimate disposal, these effluents are discharged to the aquatic environment. The degree of treatment required will depend largely upon the dilution provided by whatever receiving waters are available.

The concentrated radioactivity, whether on ion exchange resin, chemical or biological sludge, evaporation concentrate, or earth material, can be rendered innocuous only by storage and decay in a remote and shielded location. This is accomplished either by burial in a regulated "graveyard" or by dumping at sea. To provide extra shielding the radioactive material is incorporated in concrete and placed in a steel drum. For sea disposal, this also insures the material sinking to the bottom.

HIGH-LEVEL WASTES

The atomic energy industry in the United States represents a \$6 billion capital investment: of this total \$115 million has been spent on the treatment and disposal of fuel processing (high-level) wastes (28). To date about 65,000,000 gal of this high-level liquid waste have been stored in tanks. This is in comparison to an expenditure of about \$23 million which has been invested in the treatment and release facilities for low-level liquid wastes and \$35 million for handling gaseous wastes.

It is obvious that the present system of tank storage of these high-level liquid wastes and a predicted accumulated volume of one-half billion gallons by the year 2000 are virtually incompatible from an economic point of view (29). Furthermore, the hazard associated with such large quantities of concentrated wastes at the surface where they may be dispersed by damage of tanks due to earthquake, sabotage, or explosion is great. The existence of vast amounts of these high-level wastes could create a very special problem.

At the present time the waste is a liability. Perhaps at some future date some of the longer-lived isotopes such as cesium-137 and strontium-90 may have some commercial value. Even if recovery is profitable, the separation must be most effective before the waste storage problem is reduced in magnitude. It appears that most of the waste will be with us as a waste for at least the immediate future.

It has been estimated that 10 billion curies of high-level waste will be accumulated by 1980 (30). A curie is roughly the amount of ionizing radiation emitted by 1 g of radium. To handle the anticipated quantities of waste, means of disposal other than tank storage are being investigated, such as evaporation, concentration, ion exchange on clays followed by sintering, calcination, and solid fixation. Ultimate disposal must be in locations completely removed from the environment such as burial in abandoned salt domes, deep wells, or fossil waters.

Salt Formations.—Salt beds and domes occur in abundance throughout the country, in an area of more than half a million miles square, extending through eighteen states. These deposits, which are located along the south side of the Great Lakes and along the Gulf Coast, may offer the greatest possibilities.

Many salt cavities of 10 to 100 million gal capacity have been constructed with a capital investment of a few cents per stored gallon. This cost is in comparison to the present rate of expense for storage tanks of about \$0.25 to \$2.00 per gal of constructed capacity.

In the past decade, hundreds of millions of gallons of liquid petrochemical products have been successfully stored in salt cavities by various petroleum companies. These cavities have been created by washing and dissolution operations. If the mined-out cavity in a salt dome can be used successfully, the unit storage expense may be further reduced. The total space created by min-

ing rock salt during a period of 20 yr in the United States, 1934 to 1953, was equivalent to about 7 billion gal.

In essence, the advantages in salt storage lie in its strength, plasticity, imperviousness, and high solubility. Salt has considerable compressive strength but little tensile strength. The lack of tensile strength is not crucial, since tensile stress is not usually exerted around common forms of salt cavities. Salt is plastic and produces plastic flow without cracking when it is subjected to a certain shearing stress. Salt is a self-sealer. Under compressive stress, it is virtually impervious. Because salt is highly soluble in water, a huge cavity can be created very economically by simply washing the salt. Extensive laboratory and field tests and calculations have been made regarding the strength of salt structures, permeability of salt, and the temperature buildup within the cavity due to the heat liberated as a result of radioactive decay (31,32).

Deep Disposal in Shale or Porous Media.—To date, there have been several valid arguments why deep wells may prove to be an adequate means of radioactive waste disposal. The disposal of wastes through deep wells to an underground or subsurface reservoir or aquifer will present different and complicated problems. The American Petroleum Institute (33) has proposed a group of disposal wells, bleed wells, and water injection wells. To support such an effort, observation or monitoring wells would be needed to follow the spread of the disposal zone.

Storable Solids.—There are those in the radioactive waste disposal field who feel that from a safety standpoint it would be highly desirable to convert these wastes to storable solids. Some of the methods used to convert these wastes to solids are: concentration until the wastes solidify on cooling, addition of Portland cement, evaporation, and fused salt calcination, adsorption on clays and formation of clay flux mixes, fluid-bed calcination by fluidized-bed techniques, and incorporation into silicate glass matrices.

The fixation of radioactive wastes has been studied by a number of laboratories. The various methods utilized attempt to immobilize chemically the radioactive atoms themselves by sealing them within the framework of highly stable solids. One form of fixation of the fission products in the clay mineral, once it is adsorbed there, is accomplished by heating the clay to about 1700° F. A solid material with various characteristics containing the radioisotopes can be obtained by changing the base substance. The leaching characteristics are relatively low, but in many cases significant.

At the National Reactor Test Station in Idaho a waste calcination system is presently being tested (34). In this unit the primary conversion takes place in a fluidized bed waste calciner in which the liquid waste is injected into a heated fluidized bed of a granular aluminum product. Almost instantaneous dehydration and denitration of the waste take place, leaving a granular alumina solid. A volume reduction of from 7 to 10 is obtained by the conversion. It is expected that the free-flowing solids can be very safely stored in relatively inexpensive metal or concrete underground storage vaults. Perhaps here again storage within salt cavities will be the most practical.

The more difficult problems associated with the conversion of high-level liquid wastes to storable solids are the control of off-gases from the heating systems and the leaching of radioactive materials from the fixed ceramics or solids. The off-gas problem is not unsurmountable, but the successful collection of the gases is very expensive at this time. The leaching problem ceases to be a problem if the waste is canned and stored in a dry environment such as a salt cavity.

SITE SELECTION FOR ATOMIC ENERGY PLANTS

In an earlier paper published by ASCE, problems of site selection were discussed and the role and responsibilities of the sanitary engineer were emphasized (35). Since this paper was presented, the industry has gone forward at a rapid rate both in this country and abroad. Everywhere, site selection is receiving more attention than ever and for increasingly good reasons (36). Indeed, it has become an international problem of much significance professionally and politically (37,38).

Isolation of the American atomic energy plants built during World War II was not wholly for purposes of security. There was realization of inherent hazards of radioactive products and by-products and a need for isolation of plants even when this meant substantially higher costs. This isolation was continued after the war when under the first Atomic Energy Act of 1946, the AEC took over from the war agency, the Manhattan district, to direct the industry along lines of peaceful research and development as well as the production of weapons material.

Site selection was an important factor in the planning of the isolated National Reactor Testing station in Idaho and the Savannah River works in South Carolina. At both of these installations nuclear reactors and plants for chemical processing of fuel elements were built. A lesser degree of isolation was considered in the construction of other atomic plants built in the post war period. Such installations included the new fuel processing and fabrication at Fernald, Ohio, and large Scioto (Ohio) and Paducah (Kentucky) plants for reprocessing by gaseous diffusion spent fuel from which fission products had been separated.

The Atomic Energy Act of 1954 authorized relaxation of security. Also, it permitted and encouraged private industry to participate in the use of atomic energy. Subsequently, construction of the first generation of large power reactors began. Obviously, the use of atomic energy for commercial power meant that reactors had to be built reasonably near centers of consumer demand for power. This reality further emphasized the important aspects of site selection for atomic energy plants of all kinds and the inter-relationship of individual plants and units of the same industrial complex. Of special importance were plants having a high inventory of fissionable material which upon use, would create dangerous fission products of great environmental significance. Such advancement of the industry toward populated areas understandably caused concern among Congressmen and staff of regulatory agencies charged with protection of the public health and safety. The 1954 Act with its 22 references to health and safety reflects this concern.

It was clearly evident that sanitary engineers and others in the employ of regulatory agencies and industry should be prepared to meet a new brand of responsibilities—one with which many were not too familiar. This situation was equally true in other nations and especially in England and on the European continent where population density is high and the need of nuclear power to sustain the economy of nations great.

The site selected for the first large nuclear power plant with the pressurized water reactor was at a bend in the Ohio River at Shippingport, Pa., about 25 miles downstream from Pittsburgh and 7 miles upstream from the Ohio state line. Even though this reactor and its key facilities are enclosed in a steel containment shell as a precaution against the possibility of a release of fission products in case of a serious accident, this location presented site prob-

lems because of nearby populated areas, drainage on the water shed of a large interstate river and the usual problems of possible release of radioactive gaseous effluents in a valley where atmospherical drainage has certain limitations. This plant went critical in December, 1957, and has had a satisfactory record, but because of site peculiarities, costs for waste disposal facilities were high. Cooperation between company and public agencies was excellent.

Other large power plants in this first generation of nuclear reactor for power production had site peculiarities which required special consideration in layout and design of units on facilities. In each plant the reactor complex is contained in a heavy steel or concrete and steel shell. Among the largest of these power reactors are those shown in Table 5.

Under the Atomic Energy Act of 1954, permits for both the construction and operation of nuclear reactors must be issued by the AEC. The Commission has received many inquiries and registrations of concern by public and private agencies and individuals as to hazards associated with such plants. In the case of the Fermi reactor, formal objections to issuance of a construction permit were made. A long period of public hearings was held and the permit issued

TABLE 5

Reactor	Location	Type	Out-put in Megawatts	Scheduled for on Line
P. W. R.	Shippingport, Pa.	Press. Water	231 th 60 e	Dec. 1957
Consolidated Edison	Indian Point, N. Y.	Press. Water	585 th 104 e	1960
Enrico Fermi	Lagoona Beach, Michigan	Fast Breeder	300 th 100 e	1960
Dresden	Morris, Ill.	Boiling Water	625 th 180 e	1960
Yankee	Rowe, Mass.	Press. Water	392 th 110 e	1960

has continued in effect. Recently, the AEC had to insist that the location selected for a proposed nuclear reactor to supplement power to the city of Piqua, Ohio, be changed to one more removed from a built-up area of that city. There was objection by staff of Reactor Safeguards Committee to the location of the National Aeronautics and Space Administration on a site 10 miles south of Sandusky, Ohio. These are examples of the profoundness in which plant site selection as related to public health and safety is held by public agencies.

Still another rumbling of significance is the criticism by industry to certain of the criteria proposed by the AEC for selection of reactor sites. One point of concern is that attempts to restrict reactor sites on the basis of population density would be unfair to the industry because it has no control over population growth trends after a reactor complex has been built. Another is that the proposed criteria are too rigid and do not take into account possible developments in the industry which could lessen hazards which are now of concern. These are points which are subject to equitable resolution on a cooperative basis.

On September 23, 1959, an act was passed amending the Atomic Energy Commission Act of 1954 to provide for cooperation of the AEC with States.

This act authorizes the Commission to enter into an agreement with the Governor of any State which would provide for the discontinuance of the regulatory authority of the Commission with respect to any one or more of the following materials within the State:

1. By-product materials.
2. Source materials (uranium and thorium).
3. Special nuclear materials in quantities insufficient to form a critical mass.

During the duration of such an agreement, the State shall have the authority to regulate these materials for the protection of the public health and safety from radiation hazards. This amendment reserves to the Commission the authority and responsibility with respect to the regulation of production and utilization facilities, the export and import of the materials referred to above, the disposal into the oceans of waste materials and, optionally, the disposal of other materials as the Commission determines should be arranged through licensure from the Commission.

This authorization for the Commission to relegate such regulatory authority in certain areas to the States is a stepping stone in the return of health and safety control in this field to the local jurisdiction, as it has been for so long in all other health fields. The conditions for such an adoption of regulatory authority by the States are: (1) that the Governor of the State certify its willingness and ability to control such radiation hazards and; (2) that the Commission finds the State program compatible with that of the Commission for the regulation of such materials.

These significant changes in policy are likely to have a profound effect on the responsibilities which sanitary engineers in governmental agencies, industry, and educational institutions must carry. They are preparing to meet this responsibility by becoming better informed as to current operations of the industry and its problems, by getting acquainted with research and development within the industry and its plans for expansion, nationally and internationally. Staff of regulatory agencies appreciate the impact of the expanding industry on the economy of nations and prepare to assist rather than to hinder its progress. It is important that they be prepared to serve the industry in resolving its problems to such a degree that they will be invited early to participate in planning both long term and immediate programs. The continuing training programs in radiological health which for several years have been carried out by the USPHS at the Robert A. Taft Sanitary Engineering Center have been exceedingly helpful to sanitary engineers and other professionals.

Every sanitary engineer who has ever worked with industry in problems of water supply, waste disposal, housing and environmental sanitation knows the importance of a thorough appraisal of environmental factors selecting an industrial plant site. In an age when technological advances are rapid and obsolescence high, mistakes in site selection can be costly to industry and a continuing serious problem to man and his environment. The sanitary engineer by reason of his training has an appreciation of breadth of environmental problems and the need of competence in many professions to aid in resolving them. He is in a favorable position to help because by training he has a good appreciation of importance of expert advice from many professions in resolving problems of the environment and the social-political which are related to these problems. He is a good pivot between the sociological, medical, biological, and engineering professions. At the present time site selection for major re-

search, production and power reactors, and for fuel processing plants which will serve such reactors, is one of the most important areas for concentration by sanitary engineers. If such plants are well located and problems of water supply and waste treatment and disposal adequately covered, subsequent plant operational problems affecting the environment are likely to be few. A reasonable exclusion area should be planned for every major facility of this kind. Planning for community growth should take into consideration the potential hazards of such plants and controls and warnings which must be planned. Where exclusion possibilities are limited because of costs, adequate clean-up facilities for waste treatment and disposal must be planned.

Fortunately in the United States there have been no catastrophic accidents to nuclear reactors in or near populated areas. At the reactor testing station there have been incidents of a serious nature during normal operations and those planned for the purpose of obtaining information as to the extent of hazards associated with destruction of certain vital parts of a reactor.

In Canada and England, unfortunately, the record has not been as good. The Chalk River incident in December, 1953, resulted in such serious damage of the NXR reactor to require dismantling and reconstruction with the loss of fission products to the environment. The isolation of this plant was a most favorable circumstance. In England in October, 1957, at the Windscale Works in Cumberland there was overheating of the graphite moderator in an air cooled reactor as a result of insufficient instrumentation with melting and volatilization of nuclear fuel. Flooding of the reactor by water checked what could have been a calamity. This reactor has been abandoned. Eight months later extensive damage was done to Calder "B" reactor when a large turbine in test over-heated and practically disintegrated. Blasts of metal seriously damaged the reactor building, fractured water pipes and caused flooding of the building.

The number of large power reactors and fuel processing plants in populated areas of this country are so few that problems of the effect of one plane on another in case of a serious accident have not been serious. At some future date however, this situation may change. Release to the atmosphere of hazardous radioactive materials in case of a serious accident at a reactor or fuel processing plant probably would present the most serious situation affecting man and his environment. D. H. Pack and C. R. Hosler (4,38) report on a study of the possible effect of 8 nuclear reactors in a densely populated area of 40,000,000 people in the triangle formed by Washington, D. C., Hartford, Conn., and Albany, N. Y., and conclude that under conditions of prolonged stagnant atmospheric conditions the stage could be set for serious exposure to radioactive contaminants.

Now that the Navy has demonstrated the feasibility of nuclear power to propel submarines there is good reason to believe that the nuclear ship SAVANNAH now under construction for commercial surface shipping will be followed in the years ahead by many others. The wastes and nuclear fuels of these ships will present hazards and must be under very strict control. The entrance of such vessels in harbors and estuarian waters along our coasts and inland waters of the Great Lakes-St. Lawrence Seaway will present new environmental problems. It is not unlikely that in the future plants to service these vessels will be constructed along the sea coast, adding a new flavor to site selection considerations.

The ultimate disposal of high level wastes to the ground at points well below sources of fresh water—if more economical than present methods of disposal—

may be a factor of considerable importance in selecting sites for future atomic energy plants. Long distance transport of high level radioactive wastes has so much disadvantage that it is conceivable that fuel processing for a large power reactor may be done at the reactor site. Should this prove feasible another feature would be added, making site selection in the atomic energy industry a major factor in industrial decisions and in public health and safety.

Respectfully submitted,

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**DESIGN AND COST CONSIDERATIONS IN
HIGH RATE SLUDGE DIGESTION^a**

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SYNOPSIS

This paper deals with the magnitude of data available and the effectiveness of gas versus mechanical agitation and the lack of data to fix design data for high-rate-digestion tanks. The economic aspect is also presented.

INTRODUCTION

The use of vigorous agitation as an aid to digestion has surely been accepted by the sanitary engineering field when one considers the fact that there are more than 130 installations in service in The United States (as of 1960).

The bulk of these installations are of the gas recirculation type of agitation and have been added to existing plants in order to overcome a scum problem. There are any number of testimonials to attest to the success of this treatment.

There is a second advantage to be gained from vigorous agitation; this is the increased rate of digestion. There are many combinations of theories to explain this increased digestion rate which, among others, always include the fact that, with vigorous agitation, practically the entire tank is in active use,

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whereas in a conventional installation grit deposits and scum blankets materially reduce the effective volume of the tank.

Here is a possible means of reducing the cost of treatment plants. In today's high construction and financing cost market, when a small difference in cost may mean the difference between a successful undertaking and a postponement or abandonment, the designer must take advantage of every possible saving available.

Also, there are many existing plants requiring expansion, and savings may be effected by the installation of a system to vigorously agitate the digestion tank, thereby possibly eliminating the need for additional tank construction.

DESIGN CONSIDERATIONS

The question then arises—What can the designer use as criteria in the design? One manufacturer of sewage equipment will make a guarantee on the loading which the digester will successfully handle. Another will suggest a possible loading without a guarantee. The average consulting engineer, and health department official who reviews and passes on the design, wants to assure himself that the design criteria is safe and conservative, which can only be demonstrated through the results of operation of a number of plants.

DATA AVAILABLE

All the data available was assembled on results of plants which are using vigorous agitation and which are loading the digester at a rate in excess of conventional loading. This was done through personal contact and correspondence with equipment manufacturers, through a careful review of available literature, and through direct communication with plant operators.

The type of agitation presently used includes:

1. Gas recirculation through more than one point of discharge into the digestion tank, with the bottom of the discharge pipe set about 1/3 up from the bottom of the tank. (Pearth)
2. Gas recirculation through a central point of discharge into the digestion tank with the bottom of the discharge pipe set just above the bottom of the tank. (Catalytic Reduction Process-C.R.P.)
3. Mechanical agitation through propeller blade and draft tube suspended in the digestion tank. (Mech.) (Dorr-Oliver Co.)

Table 1 lists the information collected on the results of sixteen plants. Some plant results which were furnished were not listed since these were either not complete enough or did not qualify as high-rate loading. For purposes of this study, high-rate loading was set at a minimum of 0.10 lb of volatile matter per cu ft of digester capacity per day. The results reported are for the active digestion tank, not including storage, and all of the plants reported were operating at a tank temperature of approximately 90° F.

The period of test on these plants appears to be ample for the drawing of conclusions since all except Hartford Plant No. 1 have more than four cycles of loading.

TABLE I.—SUMMARY OF OPERATING RESULTS OF HIGH RATE DIGESTION TANKS

Index	Plant	Type of Agitation	Period of Test Months	Raw Sludge		Loading Lbs. V.M./Day/C.F.	Retention No. of Days	Dig. Sl. % Red. V.M.	Source of Data
				% Solids	% V.M.				
1	Hartford, Conn.	Pearth	1	7 *	69.4	0.175	18	63	PFT Bul.
2	Wilmington, Del.	Pearth	3	6	59.0	0.101	22.5	61	PFT Bul.
3	Arlington, Va.	Pearth	9	4.5	79.0	0.222	12	66	PFT Bul.
4a	Sawyer-Pilot	Gas. Rec.	2.5	4.42	74.5	0.21	10	55.8	Ref. 9
b	Sawyer-Pilot	Gas. Rec.	2.5	4.42	74.5	0.14	15	57.2	Ref. 9
c	Sawyer-Pilot	Gas. Rec.	2.5	4.42	74.5	0.10	20	58.2	Ref. 9
5	Morgan-Pilot	C.R.P.	12	7.37	60.5	0.262	10.1	41.5	Ref. 8
6	Erie, Pa. (54)	C.R.P.	12	2.8*	65.5	0.125	9.6	56.5	CPC Bul.
7	Columbus, O.	C.R.P.	10	6.6	59.2	0.164	13.9	40.4	CPC Bul.
8	Abington, Pa.	C.R.P.	2	3.3*	74.4	0.118	13.3	51.8	Plant Rec.
9	Grand Rapids, Mich.	C.R.P.	12	4.6	67.3	0.137	14.8	48	CPC Bul.
10	Tracy, Calif.	C.R.P.	5	6.0	68.4	0.122	19.8	63.5	CPC Bul.
11	Bergen Co., N.J.	Mech.**	12	3.1*	80.0	0.1087	15.7	57.3	Ref. 10
12	Bowery Bay, N.Y. Pilot Plant	Mech. (Dorr)	6	5.1	74.5	0.18	13.3	42.5	Ref. 4
13	Bowery Bay, N.Y.	Mech. (Dorr)	8	10.2	74.1	0.163	31.0	61	Ref. 5
14	Middleboro, Mass. Pilot Plant	Mech. (Dorr)	5.5	8.2	78.0	0.20	22.0	53.9	Ref. 5 and Dorr-Oliver
15	Greenwich, Conn. Pilot Plant	Mech. (Dorr)	2	8.7	78.5	0.24	18.8	60.8	D.O. Bul.
16	Riverside, Calif. Pilot Plant	Mech. (Dorr)	2	7.6	70.9	0.13	25.5	47	D.O. Bul.

* Computed by Author

** Agitated by use of Recirculating Pumps

This observer checked percentage solids by computation. Where there were none reported, these were computed. Loading and detention times and all other data were accepted at their reported values.

DEGREE OF DIGESTION

The questions immediately arise-Do these plants digest the sludge to an acceptable degree? What criteria can be used to measure this?

The most widely quoted criteria are three, all of which set a varying requirement of percentage reduction of volatile matter based on the percentage of volatile matter in the raw sludge. Fig. 1 compares these criteria.

H. E. Schlenz's curve was developed from thirteen plants studied in 1937, and is the most conservative of the three criteria and is based on results of plants with digestion capacity and allied storage capacity.

The Chicago Pump Company curve is the least conservative, but is designed for use when forecasting results of the active digester-not including carry-over digestive action taking place in the storage portion of the tank system. In an unheated storage tank this carry-over digestion, in one instance at Abington, Pa., amounts to approximately an additional 10% in reduction of volatile matter.

When an additional 10% reduction is added to the Chicago curve criteria, it approximates the Downes curve criteria (7).² The large spread of the degree of digestion attained by the sixteen high-rate plants supports R. S. Rankin's (1) observation, "There is no precise answer to the question as to what constitutes digested sludge." The ultimate disposal of the sludge will greatly influence the degree of digestion required. Sludge which is suitable digested for the plant barging the digested sludge to sea, might be unacceptable to the plant drying by vacuum filters, and sludge suitable for drying on vacuum filters may not be suitable for drying on sludge beds.

The results of all plants meet the completion of digestion criteria as established by the Chicago curve with the exception of Plants No. 8, 11, 14, and 16 which are about 8% under and Plant No. 12 which is about 25% under the Chicago curve.

VOLATILE MATTER LOADING-REDUCTION RELATIONSHIP

An exploration was made to determine if there was any fixed relationship between volatile matter loading and reduction. This possible correlation was studied from the point of view of sludge density at each of the plants, together with a possible correlation utilizing percent of volatile matter in the raw. As found by Rankin (2), there does not appear to be a definite relationship, as illustrated by Fig. 2.

VOLATILE MATTER REDUCTION-RETENTION RELATIONSHIP

Following the steps carried out by Rankin (2) in developing the chart in Fig. 3, the relationship between volatile matter reduction and the detention based on

² Numerals in parentheses, thus (1), refer to corresponding items in the Bibliography.

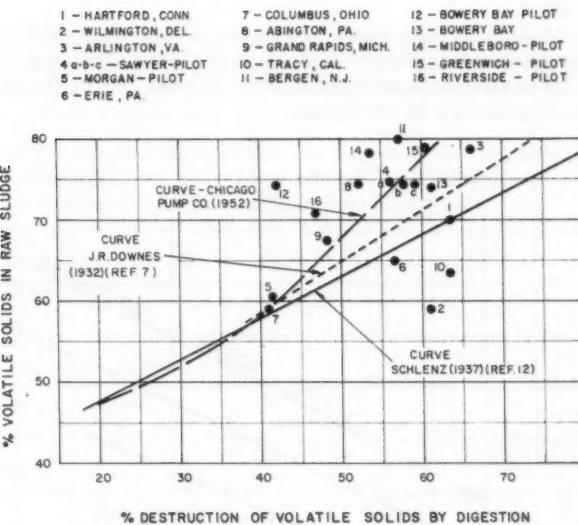


FIG. 1.—COMPARISON OF COMPLETION OF DIGESTION AT HIGH-RATE PLANTS WITH ACCEPTED STANDARDS

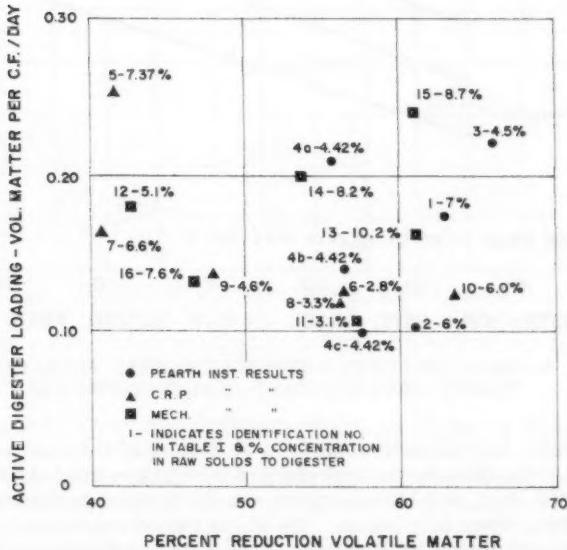


FIG. 2.—VOLATILE-MATTER REDUCTION VERSUS LOADING POUNDS OF VOLATILE MATTER PER CUBIC FOOT OF DIGESTER PER DAY

raw sludge feed was examined. Fig. 4 shows the plotting of the results of all plants on the chart.

A pattern of isograms for a range in volatile matter in raw feed was superimposed on the chart using Sawyer's three pilot plant values and Plants 5 and 7 as a base. These isograms only come close to about half of the points on the chart and this is obviously inconclusive.

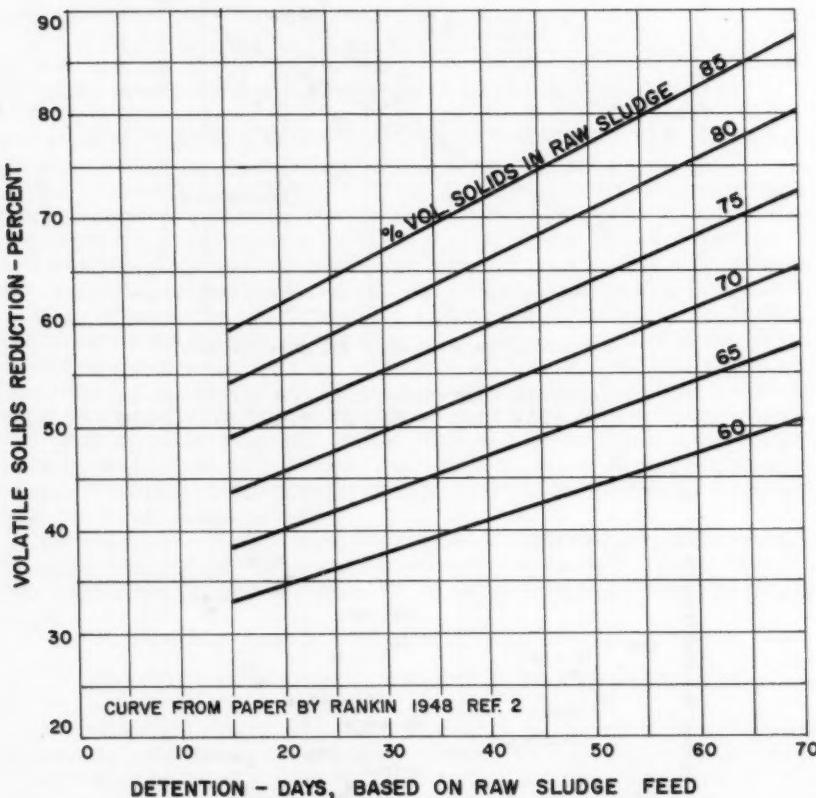


FIG. 3.—REDUCTION IN VOLATILE SOLIDS IN RAW SLUDGE ON PLANTS USING STANDARD-RATE DIGESTION PLANTS

It is believed a representative chart can be developed when and as more data is available, and the data used is back checked through a solids balance. Rankin, in developing his chart, used the operating results of eighteen plants, but examined the results of about fifty plants. The solids values reported in the plant influent and effluent and in the digesters in the eighteen plants were balanced.

INTERIM CRITERIA REQUIRED

It is desirable in the meantime to develop an approximate criteria for the design of capacity requirements on high-rate digestion tanks and to that end a comparison of actual detention periods on the plants under study was made with the detention period requirements for conventional digestion as determined by:

- (a) Rankin's chart whose acceptance is confirmed by its incorporation in the Manual on "Sewage Treatment Plant Design," (11) and
- (b) standards for Sewage Works (10 States Standards) (13).

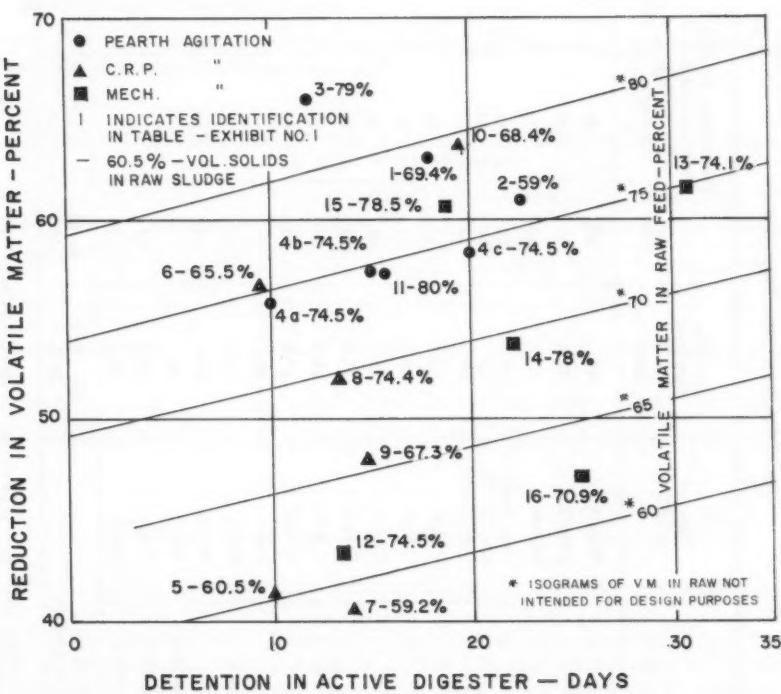


FIG. 4.—VOLATILE SOLIDS REDUCTION AND RETENTION IN ACTIVE HIGH-RATE DIGESTION TANKS

RANKIN'S CHART REQUIREMENTS VS. HIGH-RATE PLANTS

Rankin's chart gives values for detention periods including provision for storage since the basis for the chart was plant results including design for storage.

Table 2 compares the detention period of the high-rate plants under study with values in Rankin's chart for similar percentage reduction in volatile matter in raw feed. An arbitrary one-third of this capacity is considered as designed for storage and the other two-thirds is the requirement for active digestion.

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TABLE 2.—DETENTION TIME ON HIGH RATE DIGESTION TANKS COMPARED WITH CONVENTIONAL DIGESTION PERIOD

Index No.	Plant	Type of Agitation	Retention High Rate No. of Days	Theoretical Retention Conventional Rate *			Retention Time on High Rate Expressed as % of Conventional
				Total	No. Storage 1/3	Digestion 2/3	
1	Hartford, Conn.	Pearth	18	60	20	40	45
2	Wilmington, Del.	Pearth	22.5	80	27	53	42.5
3	Arlington, Va.	Pearth	12	42	14	28	43
4a	Sawyer-Pilot	Gas, Recir.	10	32	11	21	48
b	Sawyer-Pilot	Gas, Recir.	15	36	12	24	63
c	Sawyer-Pilot	Gas, Recir.	20	39	13	26	77
5	Morgan-Pilot	C.R.P.	10.1	40	13	27	38
6	Erie, Pa. (53)	C.R.P.	9.6	63	21	42	23
7	Columbus, O.	C.R.P.	13.9	39	13	26	53
8	Abington, Pa.	C.R.P.	13.3	33	11	22	60
9	Grand Rapids, Mich.	C.R.P.	14.8	36	12	24	62
10	Tracy, Cal.	C.R.P.	19.8	66	22	44	45
11	Bergen Co., N.J.	Mech.	15.7	21	7	14	--
12	Bowery Bay-Pilot	Mech.	13.3	15	--	--	--
13	Bowery Bay Plant	Mech.	31.0	43	14	29	--
14	Middleboro, Mass. Pilot	Mech.	22	17	--	--	--
15	Greenwich, Conn. Pilot	Mech.	18.8	33	11	22	86
16	Riverside, Calif. Pilot	Mech.	25.5	21	--	--	--
Range exclusive of 4c & 11 to 16 incl. Average exclusive of 4c & 11 to 16 incl.				9.6 - 22.5 14.5	32-80 48	11-27 16	21-53 32
							23% - 63% 47.5%

* As determined by Vol. Sol. in Raw and Vol. Sol. Destroyed in Rankin's Chart (Ref. 2)

This division in detention is based on the writer's examinations of designs in his office and applies to plants with sludge drying beds. The fifteen days storage is, of course, computed on the basis of the sludge feed to the primary digester and this period is materially extended where a good grade of supernatant liquor can be decanted out of the storage tank or tanks.

Inasmuch as through the use of Rankin's chart the determination of detention time for conventional digestion, applicable to high-rate plants under study, takes into consideration the variable factors such as:

- (a) Degree of digestion attained,
- (b) volatile solids in the raw feed, and
- (c) reduction of volatile solids.

The results are considered to be comparable with the actual time reported for high-rate digestion plants under study.

TABLE 3.—ESTIMATED DETENTION PERIOD STANDARD RATE DIGESTION
10 STATES STANDARDS*

Type of Plant	10 States Standards Cu. Ft. /Cap.	Dry Solids to Digester Lbs./Cap. /Day	T. S. Loading Lbs./Cf Day	Sludge Density	No. of Days of Detention		
					Total	Digestion 2/3	Storage 1/3
Primary Sedimentation	2 - 3	.12	.06 - .04	5%	52 - 78	35 - 52	17 - 26
Trickling Filters	4 - 5	.18	.045 - .036	4%	56 - 70	37 - 47	19 - 23
Activated Sludge	4 - 6	.19	.047 - .032	3%	42 - 53	28 - 36	14 - 17
Average					50 - 67	33 - 45	17 - 22
Range					42 - 78	28 - 52	14 - 26

* Ref. 13

The results indicate that retention time on high rate, expressed as percentage of conventional, varies roughly 23% to 63% and an average of 47.5% for plants with gas recirculation. Results of plants using mechanical agitation indicate that rate of digestion is about equal to the conventional rate; however, as found by Rankin (1), high loading through concentration of solids will reduce the size of the tank capacity requirements.

10 STATES STANDARD REQUIREMENTS VS. HIGH-RATE PLANTS

In order to reduce the 10 States Standard requirements for conventional digestion to equivalent detention periods, the requirements have been analyzed as illustrated on Table 3. The dry solids loadings are based on 0.2 lb per capita and the solids to the digester are equal to the expected percentage removal for the various types of plants. Raw sludge densities are estimated as though there were not extensive concentration facilities. Inasmuch as storage time is obviously included in the criteria, the values of total detention time have been divided

into digestion time and storage time on a similar basis of 2/3 and 1/3 respectively.

SUMMARY ON DIGESTION TIME REQUIRED

A summary of the comparison of detention periods required for digestion-High Rate versus Conventional-are set forth on Table 4.

The high-rate-digestion-period requirements, expressed as percentage of conventional digestion requirements as determined by the 10 States Standards, range from 34.3% to 43.2% with an average of 37.2%.

TABLE 4.—SUMMARY OF COMPARISON OF RETENTION PERIODS REQUIRED FOR DIGESTION, HIGH RATE VERSUS CONVENTIONAL

	Digestion Period Required - Days	
	Range	Average
1. 10 States Standards for Conventional Digestion	28 - 52	39
2. From Rankin's Chart for Conventional Digestion Applied to High Rate Plants Studied	21 - 53	32
3. High Rate Plants - Actual	9.6 - 22.5	14.5
Ratios - Percent		
	Range	Average
		Suggested Criteria
High Rate Versus 10 States Standards (Lines 1 to 3)	34.3 - 43.2	37.2
High Rate to Rankin's Chart (From Table No. 2)	23 - 63	47.5

The high-rate-digestion-period requirements expressed as a percentage of conventional requirements as determined by Rankin's chart, as previously stated, range from 23% to 63% with an average of 47.5%.

SUGGESTED CRITERIA

The development of an interim criteria to be used until additional data on high-rate digestion is available, as previously stated, is highly desirable. This interim criterion should be conservative in order to provide for the imponderables such as some of those suggested by Schlenz (4) which include:

- (a) Variations in quantity and quality of sludge,
- (b) allowances to offset disrupting influence of toxic wastes, and
- (c) compensation for the lack of trained personnel.

ADJUSTMENT APPLICABLE TO 10 STATES STANDARDS

- It is, therefore, conservative to consider using as a criterion, one half the digestion capacity required by the 10 States Standards for conventional digestion plus necessary storage. This criterion applied to these requirements would lead to Table 5.

TABLE 5.—COMPARISON OF REQUIREMENTS FOR DIGESTION AND
STORAGE TANKS, TEN STATES STANDARDS VERSUS
SUGGESTED HIGH RATE

Type of Plant	10 States Standards Cu. Ft./Cap.	High Rate Digestion Cu. Ft./Cap.
Primary Sedimentation	2 - 3	1-1/3 - 2
Trickling Filters	4 - 5	2-2/3 - 3-1/3
Activated Sludge	4 - 6	2-2/3 - 4

These capacity requirements include provision for storage where sludge is dewatered on sand drying beds and may be reduced if sludge is dewatered mechanically or otherwise frequently withdrawn (13).

ADJUSTMENT APPLICABLE TO RANKIN'S CHART

When complete data is available on the sludge to be digested, including volatile solids in the raw feed, the degree of digestion desired and amount of storage required, then a rational design should be carried out. It is suggested that Rankin's chart can be used to determine conventional digestion and storage-time requirements for available conditions; then, in order to be conservative, a factor of 0.40 (amounting to 60% of conventional digestion time) would be applied to determine digestion time for high-rate design. Storage time as determined for the type of dewatering and disposal requirements would then be added. It is preferable to have approximately the same volume for storage as in the active digester; this will provide facilities for ripening and compacting the digested sludge.

COST CONSIDERATIONS

The savings in construction cost through the use of high rate digestion allowing for the reduction in size and/or number of digestion tanks required, is very apparent. Another savings that may be made is through the elimination of the need for the great flexibility required in conventional digestion tanks. This flexibility was most desirable when it became necessary to take a tank out of service in order to clean out a large accumulation of scum and grit. One manufacturer reports that it has not been necessary to take any of his installations of high-rate digestion out of service. It appears that some of the flexibility, such as duplicate gas recirculation equipment and elaborate piping arrangement,

might be eliminated from the storage tank or tanks. The storage tank could be connected so that, in addition to normal transfer of solids, there would be connections whereby the tank could be used as an emergency primary digester for a limited period.

Fig. 5 is a plan of existing conventional digestion tanks at York, Pa., showing sludge and supernatant piping.

In this design, any two tanks could be used as the primary or actively heated digestion tanks and the third tank could be used as a cold tank for supernatant withdrawal and compaction and storage of the digested sludge.

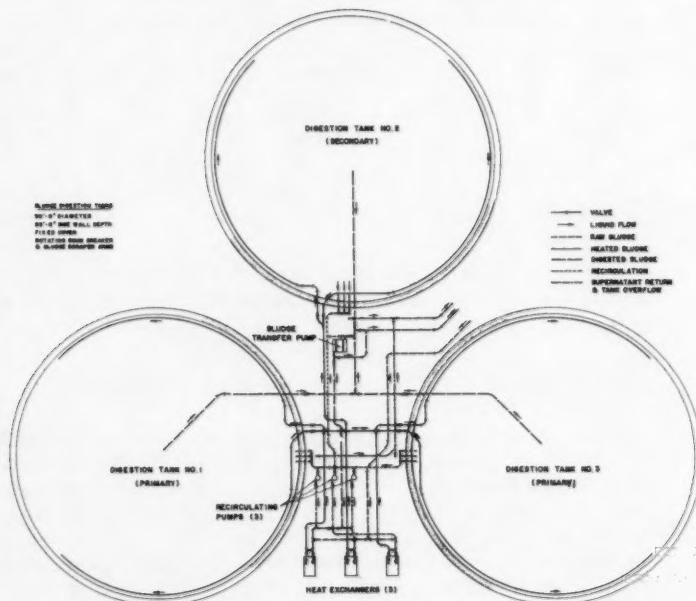


FIG. 5.—SLUDGE AND SUPERNATANT PIPING CONVENTIONAL DIGESTION TANKS AT YORK, PA.

With the design as shown in Fig. 6 adjusted for the use of high-rate digestion, one of the 90 ft diameter by 28 ft deep tanks can be eliminated and corresponding equipment and sludge and supernatant piping eliminated. The light dotted lines illustrate the savings in piping through elimination of unnecessary flexibility which in a two tank installation amounts to 25% of the sludge and supernatant piping.

ESTIMATED SAVINGS

We have taken the actual cost of three installations of digestion tanks, having population equivalent design capacities of 28,400, 61,000, and 187,000, and adjusted these to present-day costs, and analyzed the savings that may be effected

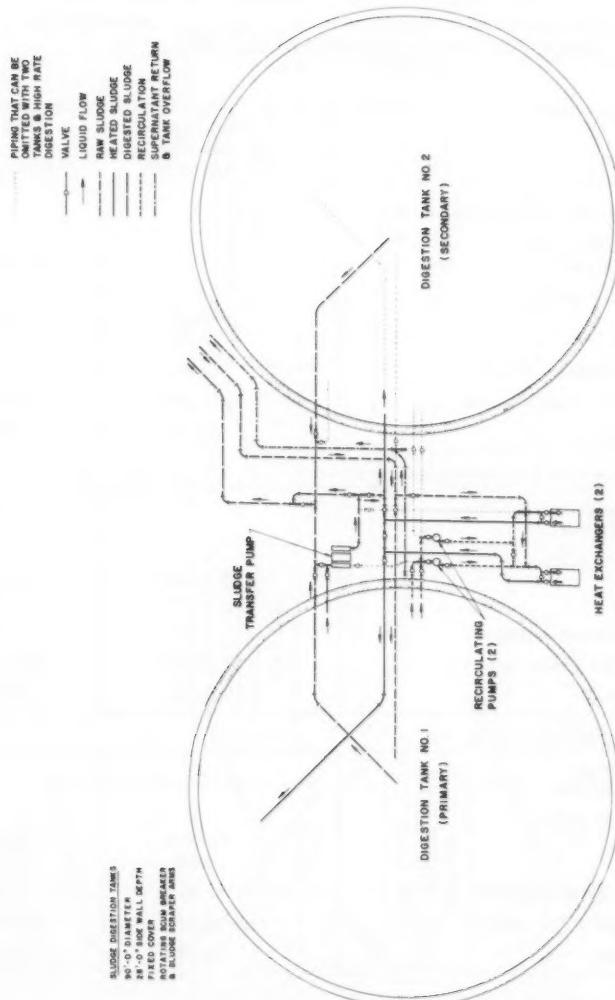


FIG. 6.—SLUDGE AND SUPERNATANT PIPING WHICH WOULD BE REQUIRED WITH HIGH-RATE DIGESTION AT YORK, PA.

through the use of high-rate digestion, as illustrated in Table 6. The cost of the high-rate installation does not include the cost of the license fee charged by one of the equipment manufacturers.

TABLE 6.—COMPARISON OF COST OF THREE EXISTING CONVENTIONAL DIGESTION TANKS AND EQUIVALENT HIGH RATE DIGESTION TANKS

	Conventional Digestion (Actual)	High Rate Digestion (Estimated)
TREATMENT PLANT AT HANOVER, PA.		
Equivalent Design Population - 28,400		
Design Capacity (CF)		
Total	120,000	80,000
Per Capita	4.23	2.82
Computed Detention - (Days)	60	45
Total Cost (1959 Price Level)	\$235,000	215,100
Cost Per Capita	\$8.25	\$7.55
TREATMENT PLANT AT LEVITTOWN, N.J.		
Equivalent Design Population - 61,000		
Design Capacity (CF)		
Total	221,000	147,000
Per Capita	3.62	2.41
Computed Detention - (Days)	45	30
Total Cost (1959 Price Level)	\$345,000	\$304,600
Cost Per Capita	\$5.65	\$5.00
TREATMENT PLANT AT YORK, PA.		
Equivalent Design Population - 187,000		
Design Capacity (CF)		
Total	560,000	373,000
Per Capita	2.99	2.00
Computed Detention - (Days)	43	29
Total Cost (1959 Price Level)	\$810,000	\$590,250
Cost Per Capita	\$4.35	\$3.15

NOTE: Capacity and Costs Include Digestion and Storage Volume.

A graph in Fig. 7 illustrates the cost per capita of design capacity on conventional and high-rate installations together with savings that may be effected on design of tanks ranging in capacity from 28,000 to 187,000 population equivalent design. This saving is estimated to range between \$25,000 and \$220,000.

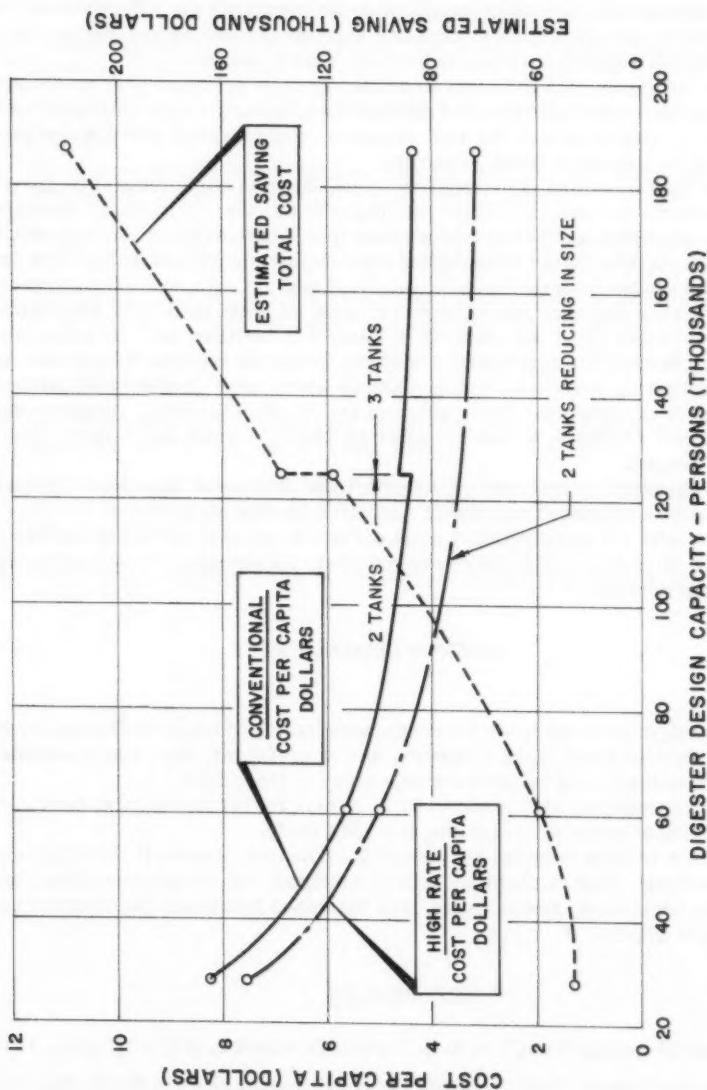


FIG. 7.—COMPARISON OF COST FOR HIGH-RATE DIGESTION VERSUS CONVENTIONAL DIGESTION

SUMMARY

As a result of this study, it is concluded that:

1. There is sufficient data available to demonstrate the effectiveness and the possibility of a reduction in capacity through the use of gas recirculation for the vigorous agitation required for high-rate digestion.
2. The available data demonstrates that vigorous agitation with mechanical devices will not increase the rate of digestion, although high loadings can be successfully treated where the raw sludge is concentrated, thereby reducing the size of the digestion tanks required.
3. The data available is insufficient in quantity and completeness to provide a fixed criteria for design of high-rate digestion tanks. It is highly desirable that equipment manufacturers collect data that is as complete and correct as possible on existing highly loaded plants for future review and study. The data collected on sludge loading should be balanced and the data collected on results of the high-rate digestion tanks should include at least sufficient information that it would allow all of the columns in Table 1 to be filled out. As pointed out previously, Rankin, in developing his chart, collected data on fifty plants but used the operating results of eighteen plants which were checked and balanced by Rankin. It is hoped that with sufficient information including complete data on the number of plants, a chart similar to Rankin's chart as shown in Fig. 4 can be developed.
4. A conservative interim criterion for the design of high-rate digestion tanks should be adopted, possibly as suggested by this observer.
5. Even with the application of a conservative interim criterion for design of high-rate digestion tanks, there are considerable savings to be effected over conventional designs.

ACKNOWLEDGEMENTS

Acknowledgment is made for the cooperation received from the Chicago Pump Company, Pacific Flush Tank Company, and Dorr-Oliver, Inc., who assembled all of the data that could be used for this study in their files.

Acknowledgement is also made to R. S. Rankin for his assistance, furnished through personal contacts, regarding his 1948 study.

The writer is also indebted to Robert M. Bolenius, James H. Blodgett and John T. Enright, Plant Superintendents of Abington, Pa., Columbus, Ohio, and Wilmington, Delaware, respectively, who furnished additional information regarding their plants.

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WASTE TREATMENT AT THE SHIPPINGPORT REACTOR

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SYNOPSIS

A comparison of the design considerations and initial performance results of the radioactive waste disposal plant at Shippingport is presented. Measured volumes and activities of various kinds of radioactive wastes during early operation of the Shippingport Atomic Power Station are evaluated in terms of the predicted waste quantities and radioactivity levels. Operational difficulties encountered during this period which resulted in redesign of portions of the system are described.

INTRODUCTION

The radioactive waste disposal facilities of Shippingport, Pa., were designed on a conservative basis to provide flexibility for handling waste materials not only from the operation of the first PWR core but, also, from reactor cores which have not yet been designed or even envisioned. Since the cost of operating a reactor may be significantly affected by the stringency of the requirement imposed for maintaining low radioactivity in the effluents from the plant, the PWR waste disposal system was designed to handle greater radioactivity than that encountered in the plant to date or expected. This permits operation of the reactor plant with low-quality fuel elements or with various casualty conditions existent, if such operation should prove desirable. As a result of

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the design and operation of the PWR waste disposal system, a better understanding has been obtained regarding the requirements for handling wastes from pressurized water reactor plants.

WASTE DISPOSAL PLANT DESIGN

Design Estimates.—During the initial phases of the design of the PWR radioactive waste disposal system, it was necessary to estimate the type, quantity, and activity of the wastes the plant would be required to handle. Since the PWR was to be an experimental plant, it was obvious that the system should be capable of operation with failed fuel elements and that the system should be as flexible as possible, since the type of fuel materials that might be used in future plants was not known. In addition, the chemicals the reactor coolant might contain or the chemicals that might be used in decontamination of the plant or individual components could not be predicted. Coolant drainage and leakage from the reactor plant constitute the largest volume of highly radioactive liquid waste. Estimates revealed that an average of 23,000 gal per month would be discharged from the reactor plant. Table 1 summarizes the quantities and sources of all liquid wastes.

From the results of in-pile loop tests of fuel elements made defective intentionally, it was estimated that the maximum activity from fission products in the reactor coolant would be $13.5 \mu\text{c}$ per ml. The estimated activity of the reactor coolant, during reactor plant operation and after a decay period of 45 days, was considered in determining the capacity of the liquid surge tanks and is summarized in Table 2. This table is based on the significant fission products predicted to exist in the coolant should 1,000 fuel elements develop pin-hole defects and the maximum amount of corrosion products expected in the reactor coolant after 3,000 full power hours of operation.

Tables 3 and 4 list estimates of the radioactive noncombustible and combustible solid waste quantities and activities, respectively. These estimates were derived from previous reactor plant operating experience at various AEC installations.

Disposal Process Selection.—Based on these estimates, a study of the most economical methods for disposal of the radioactive waste liquid indicated that some means of separating the radioactive elements from the water was necessary. The two most promising methods for separation involved either evaporation or the use of ion exchangers to remove the nonvolatile fission products, plus a gas stripper to remove the microscopic amounts of volatile fission products. Since the efficiency of the ion exchange and stripping processes was not known for typical PWR wastes, consisting of pure, deionized water containing carrier-free radioisotopes, the principal design effort was first made on the proven evaporation process.

Meanwhile, developmental work was started to resolve the unknowns associated with the ion exchange and stripping processes. Calculations had shown that a decontamination factor of approximately 1,000 was required for the highest activity expected. This developmental program, which included in-pile tests of PWR-type defected fuel elements, demonstrated that a minimum decontamination factor of 1,000 was obtainable and that resin consumption was reasonable. The program predicted that the principal contributors to gross nonvolatile water activity in the PWR wastes would be isotopes of iodine, cesium, rubidium, barium, strontium, and molybdenum, (Table 2). Other contribu-

TABLE 1.—ESTIMATE OF RADIOACTIVE WASTE LIQUID QUANTITY

Type Waste Liquid	Source	Volume (Gallons)	Interval (Days)	Time Factor ^a	Average Volume (Gallons per Month)
1. Reactor Plant Effluents	a. Plant Drainage	13,300	120	0.95	3,240
	b. Plant and Individual Loop Startup	1,350	120	0.95	323
	c. Leakage	38	1	1	1,140
	d. Sampling	2,500	30	1	2,500
	e. Decontamination Solutions and Rinse Water	14,450	120	0.958	3,500
	f. Resin Slurrying Water	4,300	45	0.958	2,750
	g. Incinerator Ash Slurrying Water	2,140	30	1	2,140
	h. Evaporation of Chemical Wastes	7,700	30	1	<u>7,700</u>
				TOTAL	23,293
2. Nonactive Waste Liquid ^b	Cold Laundry, etc.	5,650	1	1	170,000
3. Special Waste Liquid ^c	Hot Laundry, etc.	2,960	1	1	89,000
4. Chemical Waste Liquid ^d	Decontamination Fluids	7,700	30	1	7,700

^a It is estimated that the plant will be shut down for at least one-half of a month each year for refueling operations. The actual plant operating time (time factor) is, therefore, 23/24 or 0.958 of a year. ^b Estimated activity of nonactive waste liquid = 8×10^{-7} μc per ml. ^c Estimated activity of special waste liquid = 2.2×10^{-4} μc per ml. ^d Estimated activity of chemical waste liquid = $0.27 \mu\text{c}$ per ml.

^b Estimated activity of nonactive waste liquid = $8 \times 10^{-7} \mu\text{c}$ per ml.

^c Estimated activity of special waste liquid = $2.2 \times 10^{-4} \mu\text{c}$ per ml.

^d Estimated activity of chemical waste liquid = $0.27 \mu\text{c}$ per ml.

Estimated typical chemical waste solution composition:

Citric Acid	600 ppm	Paraperiodic Acid	100 ppm
Versene	600 ppm	Cr ⁺³ as Chloride	10 ppm
Detergent	300 ppm	Ni ⁺² as Chloride	10 ppm
Nitric Acid	100 ppm	U ⁺⁶	50 ppm
Sulfuric Acid	100 ppm	Fe ⁺³ as Nitrate	50 ppm
Sulfamic Acid	100 ppm	Hydrofluoric Acid	100 ppm
Na-pyrophosphate	100 ppm		

tors were expected to be zirconium, niobium, ruthenium, tellurium, and the rare earth elements.

A series of batch stripping experiments was performed in which the simultaneous removal of a gas present in bulk amounts and a gas present in trace

TABLE 2.—ESTIMATED FISSION AND CORROSION PRODUCT ACTIVITIES OF PWR REACTOR COOLANT

Isotope Group	Coolant Activity during Reactor Operation ($\mu\text{c}/\text{ml}$)	Coolant Activity 45 Days after Withdrawal ($\mu\text{c}/\text{ml}$)
Alkali Metal Fraction (Rb ⁸⁸ , Rb ⁸⁹ , Cs ¹³⁷ , Cs ¹³⁸ , Cs ¹³⁹)	1.89×10^{-1}	1.2×10^{-3}
Alkaline Earth Fraction (Sr ⁸⁹ , Sr ⁹⁰ , Sr ⁹¹ , Sr ⁹² , Ba ¹³⁹ , Ba ¹⁴⁰ , Ba ¹⁴¹)	7.2×10^{-3}	1.15×10^{-4}
Rare Earth Fraction (Y ⁹⁰ , Y ⁹¹ , Y ⁹² , Y ⁹³ , Y ⁹⁴ , La ¹⁴⁰ , La ¹⁴¹ , Ce ¹⁴¹ , Ce ¹⁴³ , Ce ¹⁴⁴ , Pr ¹⁴³ , Pr ¹⁴⁴ , Pr ¹⁴⁵ , Pr ¹⁴⁶)	2.79×10^{-4}	3.97×10^{-5}
Ruthenium-Rhodium Fraction (Ru ¹⁰³ , Ru ¹⁰⁵ , Ru ¹⁰⁶ , Rh ¹⁰⁶)	2.16×10^{-5}	7.12×10^{-6}
Zirconium-Niobium Fraction (Zr ⁹⁵ , Zr ⁹⁷ , Nb ⁹⁵ , Nb ⁹⁶ , Nb ⁹⁷ , Nb ⁹⁸)	1.54×10^{-4}	3.1×10^{-5}
Molybdenum-Tellurium Fraction (Mo ⁹⁹ , Mo ¹⁰¹ , Mo ¹⁰² , Te ¹³¹ , Te ¹³² , Te ¹³⁴ , Tc ¹⁰¹)	3.82×10^{-2}	5×10^{-7}
Halogen Fraction (Br ⁸⁴ , I ¹³¹ , I ¹³² , I ¹³³ , I ¹³⁴ , I ¹³⁵)	2.59	1.9×10^{-4}
Corrosion Product Fraction (F ¹⁸ , K ³⁸ , Mn ⁵⁶ , Na ²⁴ , Co ⁶⁰ , Fe ⁵⁹ , Ta ¹⁸² , W ¹⁸⁷ , Hf ¹⁸¹)	5.65×10^{-3}	4.46×10^{-5}
Rare Gas Fraction (Kr ⁸⁵ , Kr ⁸⁷ , Kr ⁸⁸ , Xe ¹³³ , Xe ¹³⁵ , Xe ¹³⁸)	10.62	6.8×10^{-2}
Total Gross Activity	13.53	6.96×10^{-2}
Gaseous Activity	10.62	6.80×10^{-2}
Nonvolatile Activity	2.91	1.6×10^{-3}

quantities was measured. The experiments were necessary, because the literature did not contain sufficient information for calculation of the height of a transfer unit (HTU) for various packing materials when stripping trace amounts of xenon (the principal volatile fission product predicted) from water. The

standard procedure for designing a stripping column for gases for which experimental data are not available is to make use of existing correlations, substituting the appropriate values for the diffusion coefficient and the Henry's law constant of the gas being considered. Although this method is considered valid for gases in macroscopic concentrations, its application to stripping trace quantities of dissolved gases from water was questioned. The experiments,

TABLE 3.—ESTIMATED RADIOACTIVE NONCOMBUSTIBLE SOLID WASTE QUANTITY

Source	Average Volume per Month (cu ft)	Predicted Activity ($\mu\text{c}/\text{ml}$)
1. Coolant Purification Demineralizer Resin	16	1×10^4
2. Canal Water System Demineralizer Resin	12	5.4×10^{-3}
3. Radioactive Waste Disposal System Demineralizer Resin	8	1×10^{-5}
4. Chemical Waste Evaporator Bottoms	20	27

TABLE 4.—ESTIMATED RADIOACTIVE COMBUSTIBLE SOLID WASTE QUANTITY

Source	Pounds per Week
Ordinary laboratory waste	200 to 300
Maintenance decontamination of equipment	300 to 700
Normal Range	500 to 1000
Extra, when subassembly is removed, could be	2000 to 4000
Maximum Range	2500 to 5000

It is estimated that this combustible waste will have the following average composition:

	<u>%</u>
Paper	80
Wood	10
Miscellaneous	10
	100

No data on activity level of this waste are available.

however, demonstrated that the removal of trace amounts of xenon from water could be accomplished in accordance with rates calculated by the application of the standard gas absorption formulas.

The ion exchange, stripping process was selected as representing the most economical system to install and operate. Further work on the evaporation method as a primary process was, therefore, terminated. However, a small

evaporator was included in the final waste disposal design to handle liquid wastes containing a high ionic content (such as the decontamination fluids) which would rapidly deplete the ion-exchanger resin.

PROCESS DESCRIPTION

Liquid Waste Disposal.—The system (Figs. 1 and 2) was designed to facilitate the most efficient handling of the various types of liquid wastes. Liquid wastes were separated into four categories according to their expected activity and ionic content as follows:

1. Reactor plant effluents.
2. Chemical waste liquids.
3. Special waste liquids.
4. Nonactive waste liquids.

The sources of reactor plant effluents are listed in Table 1. These liquids have a very low ionic content and, as a result, the ion exchange method of decontamination is feasible. Four underground surge tanks with a total capacity of 116,000 gal are provided to receive and hold these liquids for a maximum of 45 days. As each surge tank is filled, it is sampled and the gross volatile and nonvolatile activities are determined. A gross decay factor may be calculated and used in estimating the activity after any storage time up to 45 days. From this, the processing required to obtain a final effluent that will not exceed $1/10$ of the maximum permissible concentration for mixed isotopes in water ($10^{-8} \mu\text{c}$ per ml), as given in the National Bureau of Standards Handbook 52, can be determined. The final effluent activity is estimated by applying the decontamination factor expected for each processing step. Equipment bypass lines are provided to minimize processing time, if desirable.

Nonvolatile activity of the effluent is reduced by processing through four mixed bed ion exchangers. The ion exchangers consist of H-OH form resin packed to a depth of 4 ft in 2 ft (inside diameter) stainless steel pressure vessels installed below ground in four individual shielded vaults. Exhausted resin is backflushed to an underground resin storage tank and the new charge added through above grade connections. A resin mixing tank, valve extension rods, and connections for adding fresh resin are shown in Fig. 3. Any series or parallel combination of the four ion exchangers may be used. The design is based on reducing nonvolatile activity by a factor of 1,000 when using the four ion exchangers in series at a maximum flow rate of 20 gpm.

Volatile are separated from the effluent by processing through a gas stripping column. The construction of the gas stripper is detailed subsequently. The designed flow rate is 3 gpm which is the limiting factor in the processing capacity of the system. It was expected that the volatile activity of the effluent would be reduced by a factor of 2×10^6 .

The processed liquid is collected in one of two test tanks (Fig. 4) before final discharge to the river. Here a final sample is taken to determine the discharge flow rate to insure that blending of the processed liquid with the 53,000 gpm condenser cooling water discharge will produce a final effluent with a concentration of less than $1 \times 10^{-8} \mu\text{c}$ per ml. The effluent stream is monitored prior to dilution in the condenser overflow to provide an alarm if over-tolerance liquid is discharged. The flow rate can be controlled between 3 gpm and 25 gpm. Thus a maximum dilution factor of 1.67×10^4 can be obtained. Fig. 5 shows the blended effluent, which has passed over a mixing weir, enter-

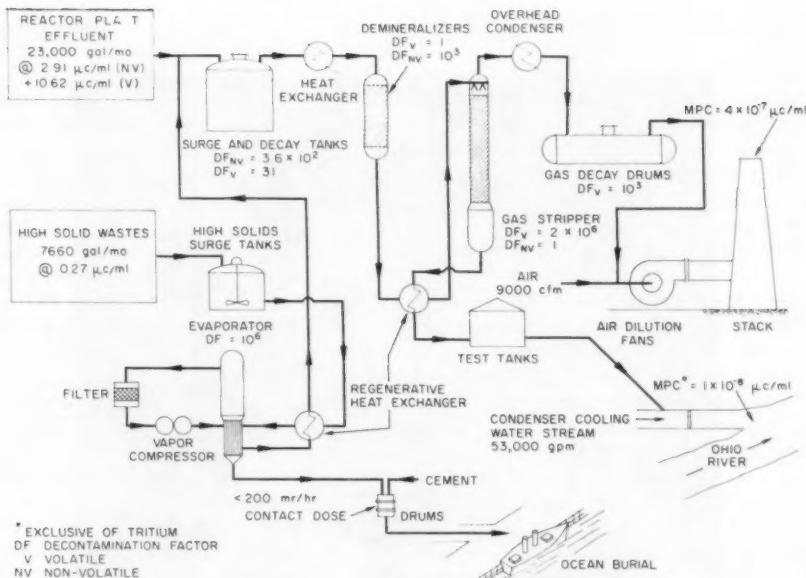


FIG. 1.—RADIOACTIVE WASTE DISPOSAL FACILITIES,
SHIPPINGPORT ATOMIC POWER STATION

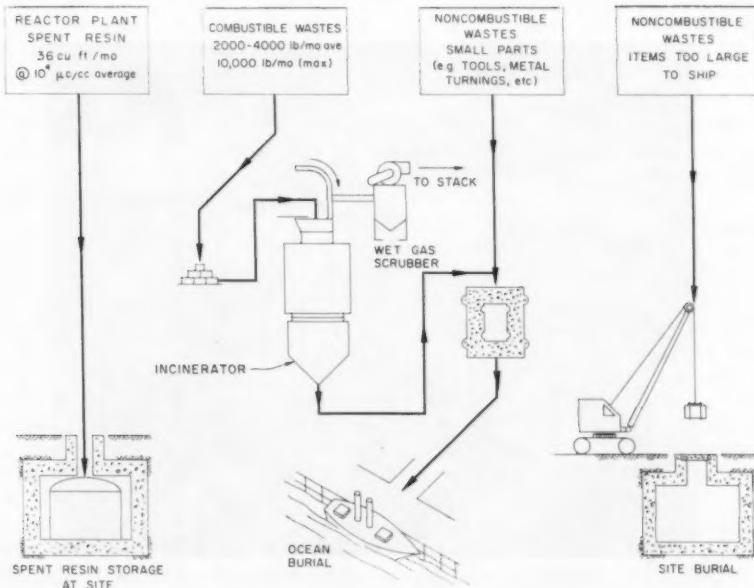


FIG. 2.—RADIOACTIVE WASTE DISPOSAL FACILITIES,
SHIPPINGPORT ATOMIC POWER STATION

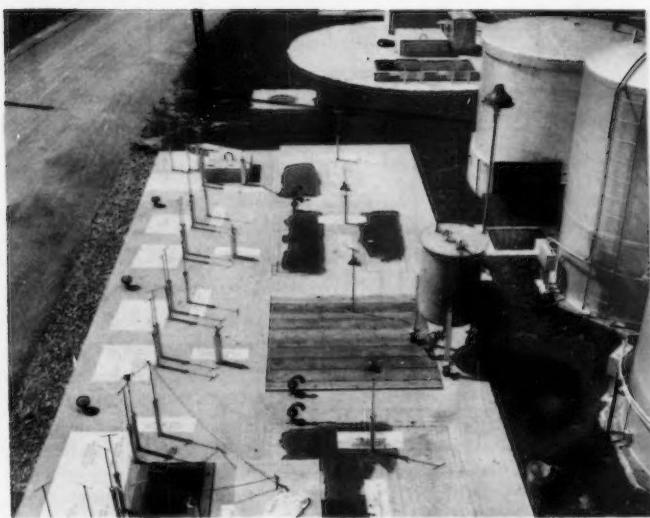


FIG. 3.—WASTE DISPOSAL ION EXCHANGER PIT



FIG. 4.—WASTE DISPOSAL YARD

ing the river. The effluent is continuously sampled at this point, and a daily composite is used for laboratory analysis.

Two chemical waste tanks with a combined capacity of 8,000 gal are provided to receive drains from the decontamination room and the sample preparation room in the reactor service building. They are also sized to accept any overflow of special or nonactive wastes. The chemical wastes were expected to have a very high ionic content because of the chemicals used in decontamination of plant components and in the preparation of samples for radiochemical analysis. As indicated in Table 1, the activity level was also expected to be high. Therefore, evaporation and concentration of the activity was chosen as the processing method for these wastes.

The internals of the chemical waste tanks are fabricated of stainless steel. The tanks are equipped with agitators and combination heating and cooling coils in order that the tanks can be used as reaction vessels if needed. The chemical waste liquid is neutralized before feeding it to a stainless steel vapor compression-type evaporator (Fig. 6). The evaporated liquid (overhead) is directed to the surge tanks where, as a safety precaution, it is reprocessed as part of the reactor plant effluents. The evaporator concentrate is mixed with cement in 55-gal drums and buried at sea.

Special waste liquids are composed of drains from the laboratories and the "hot" laundry. Two above-ground tanks equipped with agitators and having a combined capacity of 7,140 gal are provided to receive these waste liquids (Fig. 4). At the design activity, controlled discharge at a rate of from 3 gpm to 25 gpm to the effluent channel and dilution in the 53,000 gpm turbine condenser cooling water overflow reduces the activity level below the discharge tolerance. If the activity should be so great that the liquid cannot be discharged in the normal manner, it may be transferred to a chemical waste tank for evaporation.

All other liquid drains that originate in an area of possible radioactive contamination are sent to the nonactive waste tank (Fig. 4). These two tanks are equipped with agitators and have a combined capacity of 13,500 gal. At the design activity levels, these tanks may be discharged to the effluent channel at a flow rate of approximately 80 gpm where dilution by the turbine condenser cooling water overflow reduces the activity level below the discharge tolerance. This liquid may, also, be transferred to a special waste tank for controlled discharge or to a chemical waste tank for evaporation.

Gaseous Waste Disposal.—Minute quantities of radioactive gas, predominantly xenon and krypton, along with hydrogen, are brought into the radioactive waste disposal plant by two methods. Hot reactor coolant drained from the plant is discharged to a flash tank. This tank is designed in such a manner so as to quench the flashing liquid as it is depressurized. A portion of the hydrogen and fission gases contained in the flashing coolant are redissolved as the quenching process takes place. The hydrogen and fission gases not dissolved remain in the vapor space of the tank. To preclude the possibility of forming an inflammable hydrogen air mixture in this tank or in the waste disposal system, the vapor spaces of this tank and others in the waste disposal plant are continuously purged with a gas stream containing a maximum of 1% hydrogen. When the hydrogen content of the purge gas reaches 1%, the stream of gas is diverted to a catalytic hydrogen burner where the hydrogen is recombined with oxygen to form water. The burner is constructed of a 6-ft length of carbon steel pipe of a 10-in. diameter with top and bottom flanges. The active ingredient contained in the unit is a palladium catalyst deposited on a nickel wire carrier. The unit has a rated capacity of 4,000 scfh. Because the catalyst is

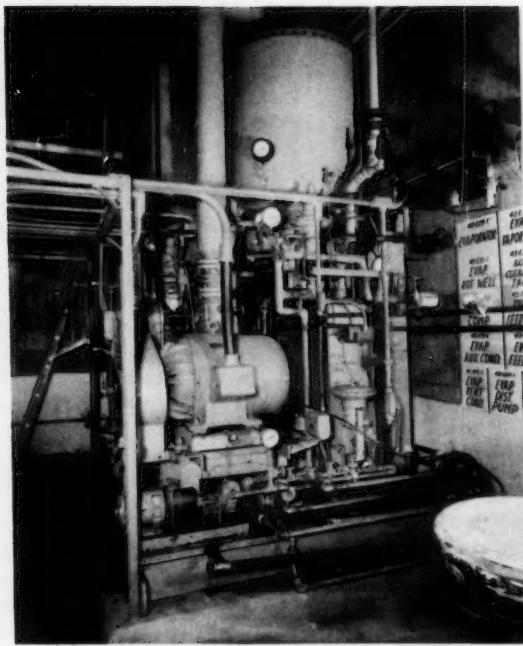


FIG. 5.—VAPOR COMPRESSION EVAPORATOR



FIG. 6.—EFFLUENT CHANNEL DISCHARGE

rendered inactive when wet, an emergency gas preheater is provided upstream of the burner in order to heat the gases to dry the catalyst when necessary. Since the catalytic reaction is exothermic, the temperature of the catalyst bed and the gas passing through the unit is increased approximately 165° C for each 0.1% of oxygen reacted. A hydrogen burner after-cooler is provided downstream of the burner to remove this heat.

The flush gas system services the four liquid surge tanks and the flash tank mentioned. Three compressors with a nominal capacity of 55 scfm each at a discharge pressure of 60 psig are provided to circulate the flush gas. The flush gas pressure is reduced to 35 psig prior to passage through the hydrogen burner and distribution to the various tanks. Since the total flush gas flow to the tanks is normally 50 scfm, operation of a single compressor is usually sufficient. A gas surge drum with a minimum operating capacity of 4,170 cu ft rides on the system to contain excess gases and supply make-up to the suction side of the compressors. The surge drum is designed to operate at pressures up to 60 psig and has sufficient capacity to maintain a constant pressure in the vapor spaces of the tanks as they "breathe" due to changes in liquid level. At infrequent intervals the "net gas make" is discharged from the surge drum to one of four decay drums where the gas is stored at 50 psig. The gas in the decay drums is stored for a sufficient period of time (60 days design) which allows the radioactivity level to decrease to a point where subsequent controlled discharge and dilution with 9,000 cfm of air from standard industrial fans will permit discharge of the gases at or below one-tenth of the maximum permissible concentration in air ($4 \times 10^{-7} \mu\text{c per ml}$), as specified in the NBS Handbook 52. The air dilution fans and waste disposal stack are shown in Fig. 7.

Dissolved gases are transported with the reactor coolant to the large underground liquid surge tanks provided for decay of the radioisotopes in the liquid. The waste liquid is first sampled in the surge tank to insure that adequate reduction of radioactivity has been accomplished before further processing is initiated. This liquid is then passed through ion exchangers to further reduce the nonvolatile activity. After passing through the ion exchangers, the waste liquid is sent to the gas stripper where the majority of the gases contained in the waste liquid are removed. The gas stripper is an all-welded type 347 stainless steel pressure vessel. The column is packed to a depth of 12 ft with 1-in. ceramic Berl saddles and is constructed of 20-in. (outside diameter), schedule 20 pipe. A suitable internal packing support and a liquid distributor are provided. Its design capacity is 1,500 lb per hr feed at an operating temperature of 200° F. The stripper operates under a slight vacuum and by means of steam stripping the gas remaining in the liquid is reduced to an insignificant amount, while the stripped gases are sent to the circulating vent gas system.

Solid Waste Disposal.—Combustible solid wastes are transported to the radioactive waste disposal building where they are incinerated. The incinerator (Fig. 2) is a cylindrical stainless steel vessel capable of burning 400 lb per hr of combustibles with a minimum carry-over of particulate matter. The flue gases pass through a wet gas scrubber where they are cooled and the particulate content is reduced. The cooled gas passes through an exhaust filter for final cleanup prior to being diluted with 9,000 scfm of air in the stack. The residual ash is dumped into an ash slurry tank located beneath the incinerator. The ash is slurried with water and pumped to one of the two resin storage tanks where it is allowed to settle out.

The noncombustible solid wastes consist of resins from the plant ion exchangers, residue ash from the incinerator, solids from strainers in the pipe

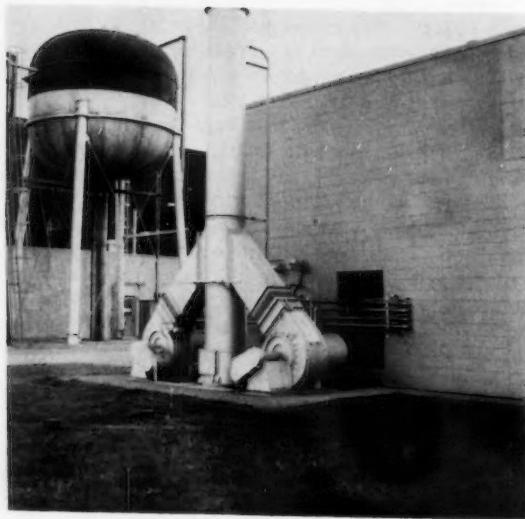


FIG. 7.—WASTE DISPOSAL STACK

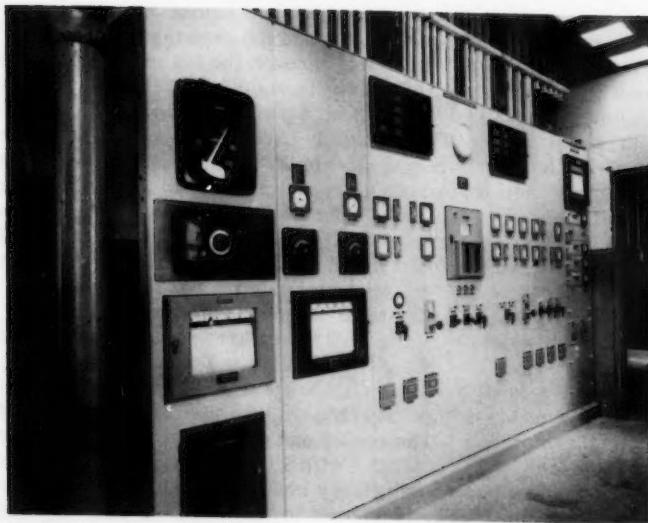


FIG. 8.—WASTE DISPOSAL CONTROL PANEL

lines, and contaminated items of plant equipment. Items in the latter category, if relatively small, are immobilized in concrete and disposed of by ocean burial. Larger items are handled on an individual basis. An area is available for burial at the plant site.

WASTE DISPOSAL PLANT PERFORMANCE

Liquid Effluents.—The predicted average monthly accumulation of reactor plant liquid effluents was 23,000 gal. In the first eight months of operation, from 2 to 14 times the design quantity was discharged per month. Special operating conditions, necessitated by the extensive testing program carried out during this period, accounted for most of this excess. The storage capacity provided in the radioactive waste disposal system was determined from a correlation of both quantity and level of activity of the liquid to be handled. The activity level of the liquid received during this period was low enough to permit immediate discharge to the river at a controlled rate. For this reason, the excess volume has not been a problem. It is of interest to note that during the months of June, July, August, and September of 1958, the quantity of reactor plant effluents became steady at about 3 times the design volume, principally because the mode of reactor plant operation was more nearly typical of a central station. During this period of continuous operation, the source of the major portion of excess liquid was determined. Approximately 12% of the excess was the result of the increased sampling of primary coolant necessitated by the test program. Another 12% was the result of frequent loop drainage for inspection of the heat exchangers and boilers as a part of the initial testing program. Plant leakage accounted for about 55% of the total excess. An extensive program was initiated to remedy this condition. Particular emphasis was placed on reducing leakage through reactor coolant system relief valves, which were known contributors. However, the waste disposal plant was designed to accommodate this excess volume.

Ion Exchangers and Gas Stripper.—Thus far, there has not been a continuing need for the use of the ion exchange and gas stripping equipment provided for processing radioactive liquid. Therefore, verification of the predicted decontamination factors is not yet possible. However, waste liquids collected in the surge tanks were processed through a laboratory ion exchanger under loading conditions similar to those in the plant waste disposal system. On these low activity level wastes, decontamination factors for nonvolatiles of from 300 to 400 have been obtained. Evaluation of development work on the removal of fission products from high-purity water by ion exchange was recently completed. Average decontamination factors, across a single resin bed, of 1,000 were reported for solutions of radioactive fission products of the type and amount possible in the PWR reactor plant effluents. In addition, this average decontamination factor was observed over periods of time which corresponded to the processing of at least 3,000 column volumes of the solution. This indicates that the original estimate of the resin exhaustion rate (8 cu ft per month) is about 7.5 times greater than can now be predicted. Considering that four ion exchangers will be used in series for waste liquid processing at PWR and that higher decontamination factors will be obtained at higher activity levels, the design decontamination factor of 1,000 should prove to be a conservative figure.

The average monthly volume of nonactive waste liquids encountered has been approximately 40% of the predicted volume of 170,000 gal. Special waste

TABLE 5.—LIQUID WASTES DISCHARGED FROM

	Nonactive Waste				Special Waste				Volume, in gal per month
	Volume, in gal per month	Average activity, in μc per ml	Maximum activity, in μc per ml	Total activity, in μc per ml	Volume, in gal per month	Average activity, in μc per ml	Maximum activity, in μc per ml	Total activity, in μc per ml	
January	33,750	3.4×10^{-7}	1.13×10^{-6}	45.58	35,700	1.7×10^{-6}	2.9×10^{-6}	24.30	87,300
February	19,373	6.6×10^{-7}	1.45×10^{-6}	47.78	23,491	1.12×10^{-6}	4.71×10^{-6}	100.40	45,900
March	31,928	2.55×10^{-7}	6.39×10^{-7}	30.85	26,279	2.75×10^{-7}	9.65×10^{-7}	27.50	311,027
April	11,330	2.95×10^{-7}	4.75×10^{-7}	12.66	20,268	4.8×10^{-6}	2.4×10^{-5}	372.83	75,500
May	84,125	2.2×10^{-7}	8.2×10^{-7}	70.11	42,240	3.52×10^{-6}	1.05×10^{-5}	562.15	134,340
June	69,440	1.82×10^{-6}	1.4×10^{-5}	478.25	39,670	7.32×10^{-6}	1.7×10^{-5}	1,125.33	60,230
July	55,290	2.2×10^{-6}	6×10^{-6}	473.57	30,747	8.55×10^{-6}	2.42×10^{-5}	1,019.80	66,650
August	72,030	7.8×10^{-7}	1.7×10^{-6}	193.69	46,960	9.76×10^{-6}	3.89×10^{-5}	1,734.31	61,510
September	58,075	6.3×10^{-7}	1.6×10^{-6}	138.08	40,940	9.47×10^{-6}	2.17×10^{-5}	1,470.06	67,280
October	35,500	8.9×10^{-7}	1.9×10^{-6}	127.13	33,865	6.77×10^{-6}	1.8×10^{-5}	869.73	35,400
November	71,555	6.43×10^{-7}	1.61×10^{-6}	174.03	39,410	3.47×10^{-6}	6.63×10^{-6}	518.00	5,000
Design	170,000	1×10^{-6}	7×10^{-6}	645	89,000	1×10^{-4}	1.7×10^{-4}	32,200	23,000

liquid received has been approximately 45% of the predicted quantity of 89,000 gal per month. The activities encountered are below design values. Both volume and activity levels are expected to increase as the degree of plant contamination increases.

Waste Disposal Vent Gas System.—Sufficient data are not available to evaluate the design of the waste disposal vent gas system. However, it is probable that larger quantities of hydrogen than the predicted 70 scf per month have been handled thus far because of the abnormal operating conditions of the testing program and the higher than expected relief valve leakage. About 3,330 standard cu ft of low-activity level gases were discharged to the atmosphere from the system during the 9-months period. Because of the low activity level, a special bypass was arranged to allow discharge at rates up to 3 scfm. The permanently installed flow controller has a maximum capacity of 1.5 scfh. The vent gas system has functioned properly in maintaining a constant system pressure, and the hydrogen content of the system has been maintained well below the explosive range at all times.

Incinerator.—The amount of combustible solid wastes disposed of in the incinerator has approximated the predicted average of 4,000 lb per month. In general, all disposable combustible items used in an area of possible contamination have been burned. The average activity level per incinerator charge has been near the lower limit of measurability.

Plant Discharge.—The criteria for the discharge of radioactive wastes are contained in a permit granted to the Duquesne Light Company by the Commonwealth of Pennsylvania. Under the terms of the permit a maximum of 6,200 μc per day and a yearly average of 1,590 μc per day of radioactivity may be discharged to the Ohio River. Because of its high tolerance level, tritium activity is determined separately and has an individual discharge limit of 300 curies per month. The amount of radioactivity discharged during the first few months of operation is shown in Table 5. It should be noted that the total amount of radioactivity discharged to date is less than that permissible during a single month. This is an indication of the margin available for safe disposal of liquids at the higher activity levels expected near the end of the reactor core life.

THE SHIPPINGPORT WASTE DISPOSAL PLANT

Reactor Plant Effluent				Activity Summary			
Average activity, μc per ml	Maximum activity, μc per ml	Total activity, μc per ml	Tritium Activity	Nonactive waste, in μc per month	Special waste, in μc per month	Reactor plant effluents, in μc per month	Total discharge, in μc per month
1.89×10^{-6}	5.1×10^{-6}	628.40	0.00368	0.00736	43.50	24.30	628.40
4.69×10^{-7}	1.12×10^{-6}	86.90	0.117	0.813	47.78	100.40	86.90
4.66×10^{-6}	1.46×10^{-5}	5,315.50	1.31	8.71	30.85	27.50	5,315.50
9.43×10^{-6}	1.3×10^{-5}	2,690.10	5.06	10.06	12.66	372.83	2,690.10
7.8×10^{-6}	1.8×10^{-5}	3,943.10	0.81	3.82	70.11	562.15	3,943.10
6.8×10^{-6}	9.8×10^{-6}	1,588.30	1.56	2.84	478.25	1,125.33	1,588.30
1.05×10^{-5}	2.7×10^{-5}	2,714.92	0.814	2.26	473.56	1,019.80	2,714.92
2.3×10^{-5}	5.83×10^{-5}	5,355.45	1.16	4.81	193.69	1,734.31	5,355.45
6.4×10^{-6}	1.63×10^{-5}	1,482.05	2.10	9.40	138.08	1,470.06	1,482.05
1.54×10^{-5}	1.58×10^{-5}	2,065.98	1.95	4.98	127.13	869.73	2,065.98
2.65×10^{-6}	2.65×10^{-6}	50.15	1.73	1.73	174.03	518.00	50.15
4.5×10^{-5}	1.7×10^{-4}	3,840	50	300			
				Allowable (Waste Disposal Plant)			
				Total Activity Discharged to Date			
				35,554.90			

ENVIRONMENTAL EFFECTS

For nearly 2 yr prior to initial criticality of PWR, an environmental radiation monitoring survey was conducted in the vicinity of the Shippingport plant by the Bettis Industrial Hygiene Department. This program has been continued during plant operation and is being conducted for the Commission by the Duquesne Light Company. In addition, the Pennsylvania Department of Health and the University of Pittsburgh have conducted independent environmental sampling programs.

The purpose of the PWR preoperational radiation survey was to collect data on the normal or background radiation levels in the area, in order to establish a basis for comparing radioactivity levels obtained during reactor plant operation and to determine if any environmental effects were detectable. This monitoring program consisted of continuous Ohio River water sampling at four locations, two upstream and two downstream from the plant. River algae samples and river bottom mud samples were also collected from the river and analyzed periodically. Radiation monitoring stations were placed strategically around the plant to continuously measure direct gamma and beta-gamma radiation levels and the radioactivity of air particulate matter. Radioactive fallout samples were collected and analyzed weekly and coil samples were analyzed quarterly.

In general, averages of gross beta activity in Ohio River water samples, both before and after reactor operation, have ranged from less than $5 \mu\text{c}$ per l to slightly greater than $30 \mu\text{c}$ per l for composite samples analyzed on a weekly basis. Of these radioactivity levels from 25% to 100% of the gross beta activity has been due to potassium-40, a naturally occurring radioisotope. The results from the two downstream sampling stations have not varied significantly from the upstream station results. The downstream results have fluctuated, giving results that were in some cases lower and in some cases higher than the upstream data. These fluctuations have shown no correlation with radioactive liquid wastes discharged to the river.

Only minor quantities of radioactive gases have been released from the radioactive waste disposal system since plant operation began. These gases

were principally of the noble gas family, that is, xenon or krypton, and no evidence of these discharges has been detected by the area monitors.

Since PWR went critical in December of 1957, the results of the environmental radiation survey have shown no indication of an increase in area radioactivity levels that could be attributed to operation of the Shippingport plant. Such a result is to be expected, based on the known levels of radioactivity actually discharged to the environment from the reactor plant and discussed previously.

OPERATIONAL PROBLEMS

Evaporator.—Difficulties were encountered in the operation of the waste disposal evaporator during the "shakedown" period, but it is now operating satisfactorily. This unit is of the vapor compression type.

During initial operation of the evaporator oil was detected in the distillate. As a result of overheating, the compressor shaft seals deteriorated. A small oil cooler was installed in the lubricating oil system to maintain a suitable temperature in the vicinity of the shaft seals. A typical decontamination solution was used in testing the evaporator (Table 1, Note c). Foaming and carry-over were extensive because of the high detergent content. An antifoam agent was suggested based on laboratory experiments and proved adequate in subsequent testing.

Hydrogen Burner.—During one of the initial plant cooldowns the hydrogen burner was inoperative. Investigation of the malfunction indicated that the catalyst, which is palladium and platinum on a nickel wire carrier, was being poisoned by either moisture-induced rust or oil contamination. The source of the contamination was service air which was added to the vent gas system during initial operations to supplement the gas in the surge drum. This was done to assure smooth operation of the system's compressors and a steady supply of flush gas. A high-efficiency filter was installed in the inlet line of the hydrogen burner and, also, at the service air connection to the surge drum in order to maintain a clean system and to insure that a clean, dry gas mixture was passed through the catalytic hydrogen burner. The filter increased the effective operating time of the catalyst. Further investigations aimed at achieving optimum system efficiency are in progress.

Ion Exchangers.—Initial operation of the system provided evidence that the ion exchangers were not passing waste liquid at their design flow rate. An investigation led to the conclusion that the ion exchanger internal filters were becoming clogged by particulate matter from the system's surge and decay tanks. A flushing procedure was developed for the system which increased the flow rate to the design value.

Incinerator.—In the original design of the combustible waste disposal system, the residue was discharged to an ash slurry tank and the slurry was then pumped to the resin storage tanks for final disposal. The presence of small metallic objects in the combustible material charged to the incinerator caused considerable damage to the slurry pump. Consequently, to collect these non-combustible materials, a screen was installed in the suction line leading to the ash slurry pump. However, the screen and strainer became clogged frequently, necessitating considerable maintenance work. Thus, the separation of non-combustibles continued to be a problem.

Because of the extreme care required to eliminate noncombustibles from the materials charged to the incinerator, extensive handling of radioactive material was necessary. Since the disposal plan for noncombustibles required a drumming operation, the possibility of drumming the incinerator residue was investigated. This would eliminate the need for complete separation of non-combustibles and, therefore, minimize handling of these radioactive materials. In addition to simplifying the disposal of solid wastes, a considerable savings could be realized. The cost of sea burial is estimated to be appreciably less than the cost of storage space in the underground resin storage tanks. Consequently, a scheme for the direct drumming of incinerator residue was devised. The ash slurry tank was removed and piping revised so that a 55-gal drum with a 30-gal drum inserted could be supported on a portable platform jack. This jack is used to force the 55-gal drum against a fabricated flange below the incinerator blast valve. A chain hoist, or an I-beam monorail, was installed to lift drums in and out of the incinerator pit. Operationally, enough ash is discharged into the inner 30-gal drum to fill it. After the incinerator has cooled, and with the wet gas scrubber operating, treated water is sprayed down through the incinerator and into the ash drum to dampen the ash and eliminate the hazard of radioactive dust. The drums are then removed from below the incinerator, filled with ready mixed concrete, and shipped to the ocean for burial along with the drummed noncombustible wastes.

Chromate Bearing Wastes.—The facilities for disposal of chemical wastes were provided to reduce the activity level in wastes of high ionic content. However, the specific problem of removing toxic chemicals from the various liquid wastes was not anticipated. Potassium chromate is used as a corrosion inhibitor in all the cooling water systems at the PWR. The Commonwealth of Pennsylvania's discharge tolerance for the chromate ion is extremely low (0.05 ppm). The leakage volume of chromated water is small and is not a problem in the case of effluents discharged directly to a chemical waste tank for evaporation. However, chromates have been detected in both the nonactive waste tanks and the surge tanks.

It was apparent that the large volume of nonactive wastes could not be evaporated on a continuous basis. Utilizing the chemical waste tanks as reaction vessels, a precipitation-flocculation process was developed which reduces the chromate concentration in the decantation to the discharge tolerance. The load on the evaporator was, thus, reduced to the volume of the residual slurry. Subsequently, a change was made in the nonactive drain piping to eliminate the source of chromate contamination.

The concentration of chromate in the liquid in the surge tanks is more than adequately reduced by processing through the ion exchangers. However, gross amounts of chromate will cause early exhaustion of the ion exchange resin. During certain conditions of cooling system loading, the open cooling tower in the waste disposal yard overflowed into the yard trenches. For a time this overflow was handled by educting it from the trenches. The tower overflow capacity has since been increased, and the chromate concentration of the cooling water has been decreased by using a combination chromate-phosphate treatment to inhibit corrosion. Chromate-bearing wastes are now being handled without difficulty.

Vacuum-Relief Protection.—Seven commercial combination pressure-and-vacuum-relief valves were installed in the system for protection of equipment in the event that design pressure or vacuum limits are exceeded. These seven

valves relieved into a common header which contained a master pressure-vacuum valve set at a wider range of pressure. Pre-installation tests performed on these valves indicated that they leaked excessively. Although they were returned to the vendor for repair, a detailed examination of their design indicated that it would be difficult, if not impossible, to maintain these valves leak-tight over an extended period of time. No other commercial valve could be found which would perform any better than these valves under the design conditions of 4 psig pressure and 3 oz per sq in. of vacuum. To insure that the gas discharged from the plant does not exceed 10% of the maximum permissible concentrations as listed in NBS Handbook 52, the effluent gas if at design conditions, after 60 days decay, is discharged at a controlled rate of 0.9 scfh maximum and blended with 9,000 scfm of air prior to discharge to the atmosphere. It is obvious that even a very small leak of relatively undecayed gas (at design activity) from the relief valves could result in exceeding the allowable tolerance.

To eliminate the possibility of relief valve leakage, the master relief valve was replaced with a loop seal. This seal was designed to provide the necessary 4 psig protection, and its discharge was directed to the stack. Alternate means of providing vacuum protection are being investigated. In the meantime, until such time that the radioactivity level becomes significant, the areas about the other relief valves are being closely monitored.

CONCLUSIONS

As a result of the design and operation of the PWR radioactive waste disposal system, a better understanding of the requirements for handling wastes from pressurized water reactors has been obtained. One important lesson learned is that the system must be flexible to the extent that high-quantity, low-activity wastes, as well as low-quantity, high-activity wastes, can be handled without restricting reactor plant operation. This is particularly true if the power plant is operated both as a central station and, at times, as a peak-load station. It is also important to consider the disposal requirements for any toxic chemicals that may be used in the plant.

Although several problems were encountered in the initial operation of the system, it must be recognized that only actual plant testing could determine whether these problems exist and, if so, their magnitude. In general, these problems did not prove serious. It must be concluded that the problems that occurred during initial testing and operation were minor considering the size and developmental nature of the installation. An important part of the information desired for future design work, that is, verification of decontamination factors and determination of optimum processing cycles, will only become available after an extended operating period with higher activity level wastes.

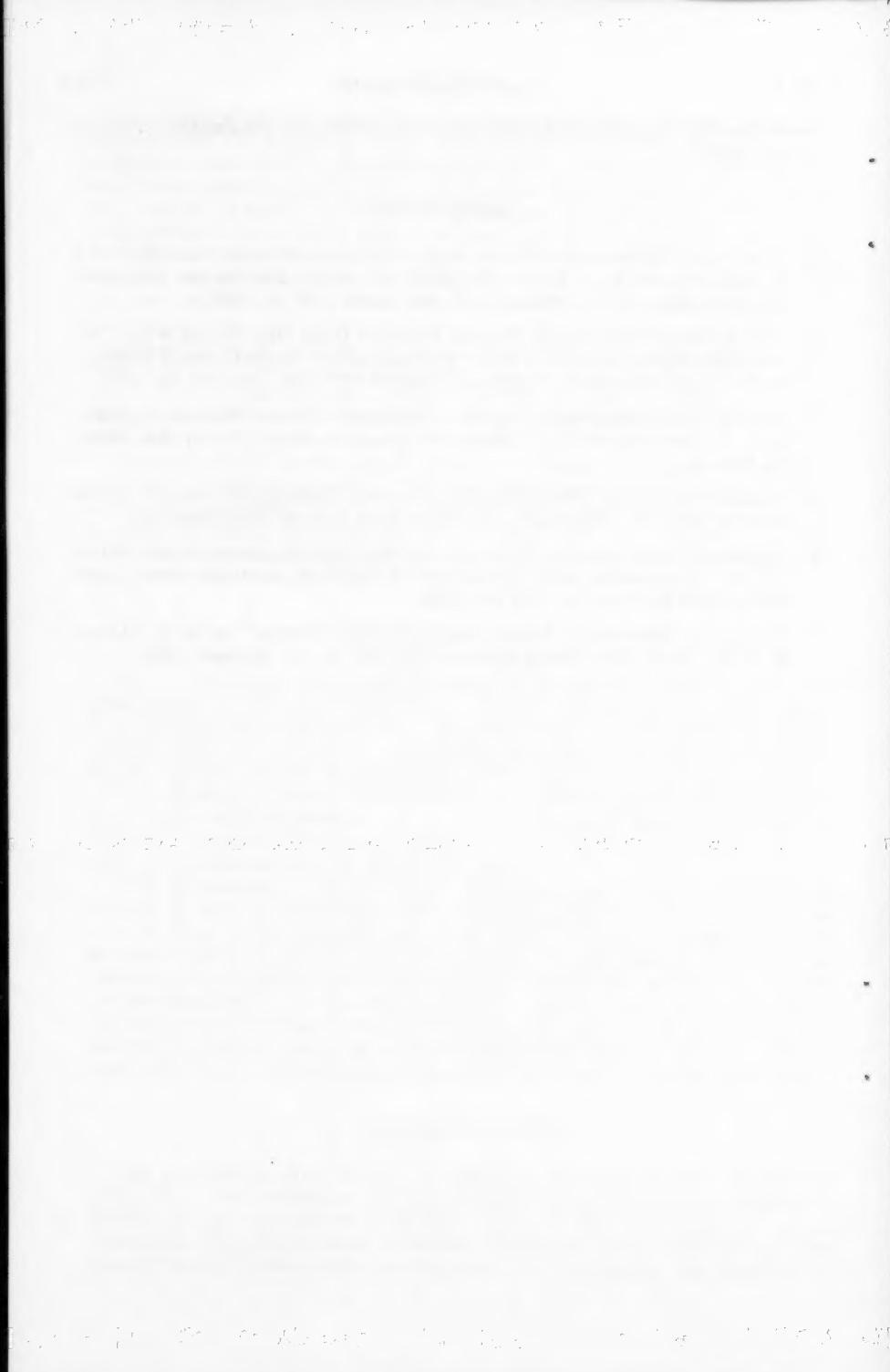
ACKNOWLEDGMENTS

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house Electric Corporation for permission to publish the information contained in this paper.

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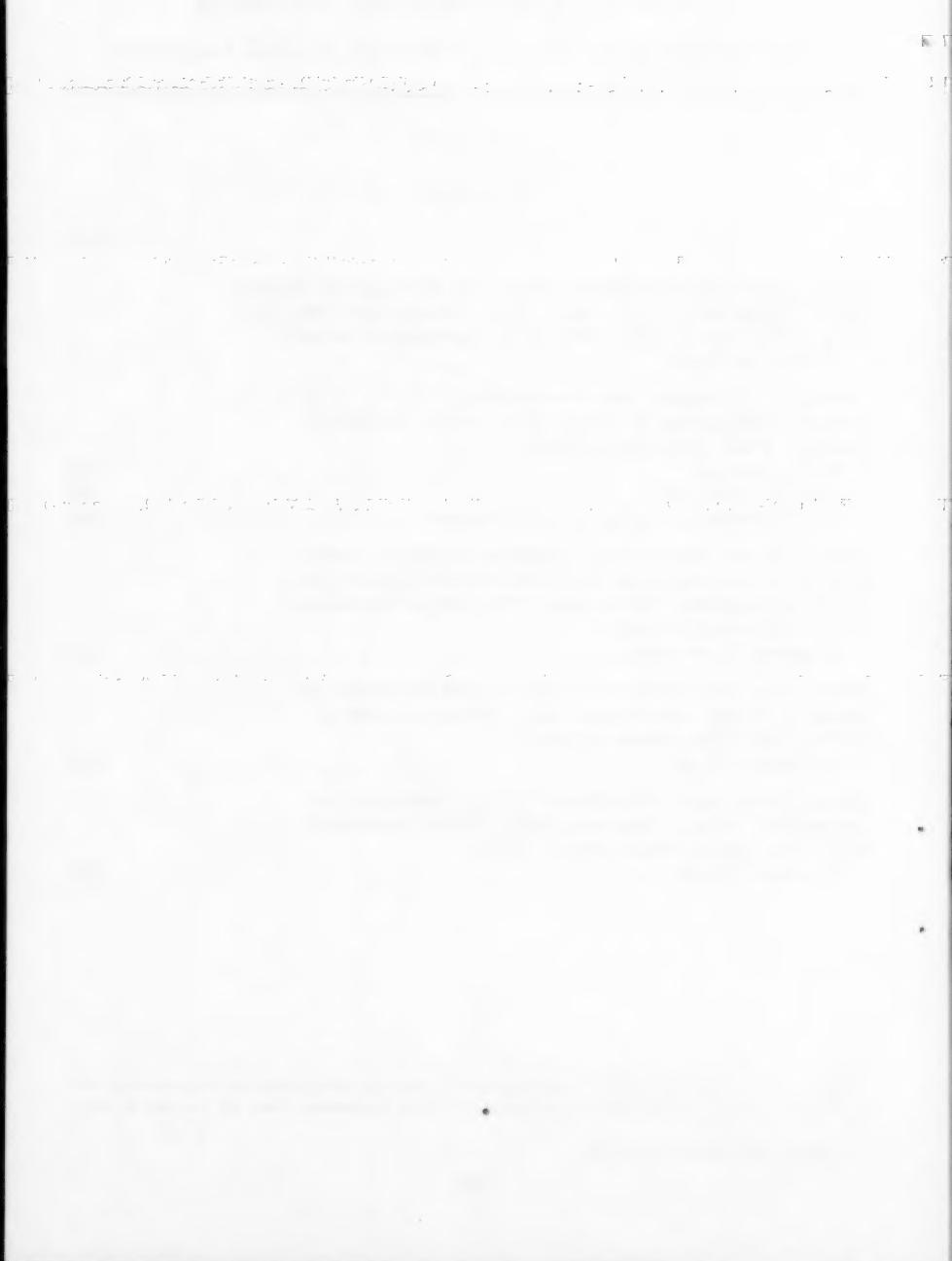
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*There will be no closure



ABSORPTION OF OXYGEN FROM AIR BUBBLES IN WATER^a

Discussion by A. Pasveer and A. L. Downing
Closure by W. Wesley Eckenfelder, Jr.

A. PASVEER.¹—In studying this very interesting paper and being exposed to its stimulating effect, the writer was challenged by the following statement:

"Since it is not possible to independently evaluate the individual film coefficients (viz. of formation, rise and release), an overall coefficient, K_L , is usually employed, which can be related to the depth of the aeration column and to the rising velocity of the bubbles."

This statement gives the essence of the difficulty in the study of the bubble-aeration process. It is evident that in a process which is a complex of at least three phenomena, a clear insight in what really happens may be obscured, which necessarily may lead to correlations of a nature as shown in the paper.

In the following it will be shown that, as may be expected, $K_L b$ is a constant during the rise of the bubble. As a further result it will be shown that the influence of the formation and release of the bubble on K_L is not very important. In the correlation between K_L and depth, another factor proves to be involved, namely the decrease in the oxygen content of the rising air bubbles.

During the rise of the air bubble there is a continuous variation of boundary layers. For the mathematical treatment this continuous variation may be considered to be replaced by a variation of a different kind in which the boundary layers remain at rest during a certain time (t'), after which they suddenly become mixed with the remainder of the liquid and are replaced by other layers. During the time t' , the bubble rises over the distance h' ($= t' v_1$).

According to the Stefan equation the quantity of oxygen diffused from a gas into a liquid after a time t , when at the interface there is in the monomolecular liquid layer a concentration C_{Ls} , is

$$Q_d = 2 A (C_{Ls} - C_L) \sqrt{\frac{D_L t}{\pi}} \dots \dots \dots \quad (14)$$

The rate of diffusion is then

$$\frac{dQ}{dt} = A (C_{Ls} - C_L) \sqrt{\frac{D_L}{\pi t}} \dots \dots \dots \quad (15)$$

^a July, 1959, by W. Wesley Eckenfelder, Jr.

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For an air bubble with, at the beginning, a quantity of oxygen Q_b in the bubble, the rate of decrease in this quantity then is (for $C_L = 0$)

$$-\frac{dQ_l}{dt} = A_l C_{Ls} \sqrt{\frac{D_L}{\pi t}} \dots \dots \dots \quad (16)$$

The term C_{Ls} may be written as $\frac{V_{O_2l}}{V_l} C_{atm}$, C_{atm} being the saturation value of oxygen in water under pure oxygen at atmospheric pressure. The term V_{O_2l} may be written as Q_l/f , where f is a conversion factor for units of volume into units of weight. Eq. 16 then may be rewritten as:

$$-\frac{dQ_l}{Q_l} = \frac{A_l}{V_l} \frac{C_{atm}}{f} \sqrt{\frac{D_L}{\pi}} \frac{1}{\sqrt{t}} dt \dots \dots \dots \quad (17)$$

Integration of Eq. 17 over the time t' gives for the quantity of oxygen left in the air bubble after a rise of h' (Q_{lh}') (assuming constancy for A_l/V_l):

$$-\ln Q_{lh}' = 2 \frac{A_l}{V_l} \frac{C_{atm}}{f} \sqrt{\frac{D_L}{\pi}} \sqrt{t'} + K \dots \dots \dots \quad (18)$$

(at $t = 0$, $Q_{lh}' = Q_l$, so K (the integration constant) = $-\ln Q_l$).

Eq. 18 may then be written as

$$\ln \frac{A_l}{Q_{lh}'} = 2 \frac{A_l}{V_l} \frac{C_{atm}}{f} \sqrt{\frac{D_L}{\pi}} t' \dots \dots \dots \quad (19)$$

from which

$$Q_{lh}' = Q_l 1^{-x} \dots \dots \dots \quad (20a)$$

and

$$x = 2 \frac{A_l}{V_l} \frac{C_{atm}}{f} \sqrt{\frac{D_L}{\pi}} t' \dots \dots \dots \quad (20b)$$

For a second rise over a distance h'

$$Q_{lh_2'} = Q_{lh}' 1^{-x} = Q_l 1^{-2x} \dots \dots \dots \quad (21)$$

and after a rise over $n h' = h$, the quantity of oxygen left in the air bubble is

$$Q_{lh} = Q_l 1^{-nx} \dots \dots \dots \quad (22)$$

In the time $t = h/v_b$ the quantity of oxygen diffused from the air bubble Q_{dh} is:

$$Q_{dh} = Q_l - Q_{lh} = Q_l (1 - 1^{-nx}) \dots \dots \dots \quad (23)$$

from which

$$\ln \left(\frac{1 - Q_{dh}}{Q_1} \right) = - \frac{h}{h'} 2 \frac{A_1}{V_1} \frac{C_{atm}}{f} \sqrt{\frac{D_L h'}{v_b}} \quad \dots \dots \quad (24)$$

If Q_b is taken as unity, then Eq. 24 gives for Q_{dh} the part of the oxygen that is diffused from the air bubble after the passage through the water column h .

If instead of the Stefan equation, for the rate of diffusion of the oxygen from the air bubble, the Lewis and Whitman equation is used, it has to be recognized that in this case C_{Ls} is not a constant. The Lewis and Whitman equation therefore is valid only for the short time dt :

$$dQ = - dQ_1 = K_L b A_1 C_{Ls} dt \quad \dots \dots \quad (25)$$

Again introducing $C_{Ls} = \frac{V_{O_2 l}}{V_1} C_{atm}$ and $V_{O_2 l} = \frac{Q_1}{f}$ Eq. 25 may be written as

$$- \frac{dQ_1}{Q_1} = K_L b \frac{A_1}{V_1} \frac{C_{atm}}{f} dt \quad \dots \dots \quad (26)$$

on integration over a rise h , that is after the time t , Eq. 26 becomes

$$- \ln Q_{lh} = K_L b \frac{A_1}{V_1} \frac{C_{atm}}{f} t + K \quad \dots \dots \quad (27)$$

at $t = 0$, $Q_{lh} = Q_1$, so $K = - \ln Q_1$.

Eq. 27 may then be written as

$$\ln \frac{Q_{lh}}{Q_1} = \ln \left(\frac{1 - Q_{dh}}{Q_1} \right) = - K_L b \frac{A_1}{V_1} \frac{h}{v_1} \frac{C_{atm}}{f} \quad \dots \dots \quad (28)$$

In the case where $C_L > 0$ the second part of the Eq. 28 has to be multiplied by $C_{Ls} - C_L / C_{Ls}$. This is mathematically correct but not quite true. Deviations are important in the conditions where C_L is not near zero, together with $d_b < 0.12$ cm and $h > 150$ cm. In these conditions a more complicated mathematical treatment has to be used. By determining h , A_1 , V_1 , v_1 , Q_{dh} and C_L , $K_L b$ and h' can be computed.

In Table 1 the results of experiments are shown in which Q_{dh} was determined by volumetric analysis of the air that had passed through the water column.

From Table 1 it may be concluded that in these experiments for water-column depths greater than 100 cm, the influence of the formation and release of the air bubbles was so small that the decreases of this influence on K_L with increasing depth falls within the deviations inherent to the experiment.

An approximate value of $K_L b$ independent of h may be assumed to have a value somewhat below the mean of the values of K_L for $h \geq 100$ cm.

A marked correlation of K_L with the depth of the water column is only found when, in computing K_L , the decrease in the oxygen content of the rising air bubble is ignored. The last column in Table 1 shows that the rate of renewal of the boundary layers at a rising air bubble is very high. Hence n has a high value.

Eq. 18 (and those following) show that the decrease in oxygen content in the rising air bubble may be considerable, this having its effect on the oxygen

absorption by the water. If this effect is not included in the diffusion formula for a rising air bubble, its influence naturally works on the values found for K_L .

From a comparison of Eq. 24 with Eq. 28 it follows that

$$K_L b = 2 \sqrt{\frac{D_L h}{\pi v_1}} \dots \dots \dots \quad (29)$$

The values for $K_L b$ computed in Table 1 are twice as high as those given in the paper, evidently because of the use of this relation instead of

$$K_L b = \sqrt{\frac{D_L h^r}{\pi v_1}} \dots \dots \dots \quad (30)$$

Indeed in the Stefan form the general diffusion equation is

$$Q_d = A(C_{Ls} - C_L) \sqrt{\frac{D_L t}{\pi}} \dots \dots \dots \quad (31)$$

Eq. 31 is valid for the diffusion from a quiescent column of water with, at $t=0$, a concentration C_{Ls} into a quiescent column of water with concentration C_L (columns of infinite length). In the case, however, in which the column with

TABLE 1.—ESTIMATE OF APPROXIMATE $K_L b$ IN CENTIMETERS PER HOUR

Data of bubbles used			$K_L(b)$ calculated from experiment with Eq. 28 (= K_L' , influence of formation and release included)							Approximate value for	Approximate value for
Average long/short cm. axis	V_b cm/sec	$\frac{Ab}{Vb}$ cm	$h=25$ cm	50	100	150	200	300	$K_L(b)$ cm/hour	h^r cm	
0.06/0.06	9.5	100	99	86	70	-	(58) ³	(53) ³	60-70	0.87-0.64	
0.154/0.134	26.1	40.9	172	190	163	155	159	160	155	0.36	
0.29/0.171	25.4	24	-	-	167	-	188	178	175	0.27	
0.62/0.31 ²	25.-	13	-	-	191	-	193	214	190	0.23	

1) brandol 60

2) apertures 0.05 cm.

3) These figures are too low because of inhomogeneity of the air bubbles used.

concentration C_{Ls} is thought to be stirred so that in the boundary layer there is a constant concentration of C_{Ls} , then according to Stefan^{2,3} (and to P. V. Danckwerts⁴) the diffusion equation

$$Q_d = 2 A(C_{Ls} - C_L) \sqrt{\frac{D_L t}{\pi}} \dots \dots \dots \quad (32)$$

² Stefan, Wiener Sitz, 77, 371, 1878; and 79, 161, 1879.

³ "Diffusion dans les Liquides," by Ducleauz, Paris, 1936.

⁴ P. V. Danckwerts, Transactions, Faraday Soc., 46, 701, 1950.

is valid. In this last example, which refers to the diffusion of oxygen from air into quiescent water, the concentration in the monomolecular water layer at the boundary constantly is C_{Ls} .

A. L. DOWNING.⁵—A most useful service has been performed by Mr. Eckenfelder in demonstrating that data in the literature on the absorption of oxygen from air bubbles can be correlated in terms of the Sherwood, Schmidt, and Reynolds numbers and the depth of liquid (Eq. 9), and that from this correlation it can be deduced that the mass-transfer coefficient K_L , is proportional to the bubble velocity and inversely proportional to the cube root of the depth and to the square root of the Schmidt number (Eq. 10). The dependence of K_L on bubble velocity can be seen directly by plotting published values of K_L and velocity for given experimental conditions against the diameter of the bubbles, and in Fig. D1 are shown some data,^{6,7,8,9} plotted in this way, which were not taken into account in the derivation of Eqs. 9 and 10. It is seen that the data of Hammerton and Garner⁶ and of Garner and Hammerton⁷ and those of Coppock and Micklejohn⁸ are in quite good agreement with Eq. 10; the data of Philpott,⁹ however, agree less well. All the data show a tendency for the value of K_L to decrease with increasing size of bubbles in the range of 0.3 cm to 0.8 cm., whereas the velocity remains approximately constant.

A somewhat similar correlation to that given by Eq. 9 has been proposed by Calderbank¹⁰ to account for the results of experiments with aerated mixing vessels and sieve plate columns, in which several sparingly soluble gases were absorbed in or desorbed from a number of solvents of different viscosity. It was found that there was a linear correlation between the mass-transfer coefficient, K_L , and the diffusivity, D_L , raised to the power 0.86. However, for different solute gases in aqueous solutions of substantially constant viscosity, μ ,

$$K_L \propto D_L^{0.5} \dots \dots \dots \quad (33)$$

and for a given solute in solvents of different viscosity

$$D_L \propto 1/\mu^{0.74} \dots \dots \dots \quad (34)$$

Thus

$$\begin{aligned} K_L &= a D_L^{0.86} = a D_L^{0.5} D_L^{0.36} = a D_L^{0.5}/(\mu^{0.74} 0.36) \\ &= a D_L^{0.5}/\mu^{0.27} \dots \dots \dots \quad (35) \end{aligned}$$

where a is a constant of proportionality. Then, if the data are to be described by a correlation in terms of the Sherwood, Schmidt, and Reynolds numbers, this must take the form

⁵ Water Pollution Research Laboratory, Stevenage, England.

⁶ "Gas Absorption from Single Bubbles," by D. Hammerton and F. H. Garner, Transactions, Inst. of Chem. Engrs., 1954, Supplement, p. 32.

⁷ "Circulation Inside Gas Bubbles," by F. H. Garner and D. Hammerton, Chem. Engrg. Science, 1954, 3, 1.

⁸ "Behaviour of Gas Bubbles in Relation to Mass-Transfer," by P. D. Coppock and G. T. Micklejohn, Transactions, Inst. of Chem. Engrs., Vol. 29, 1951, p. 75.

⁹ "Investigation of Some of the Applications of Ultrasonic Vibrations in Public Health Engineering," by J. A. Philpott, Ph.D. Dissertation, Univ. of London, 1952.

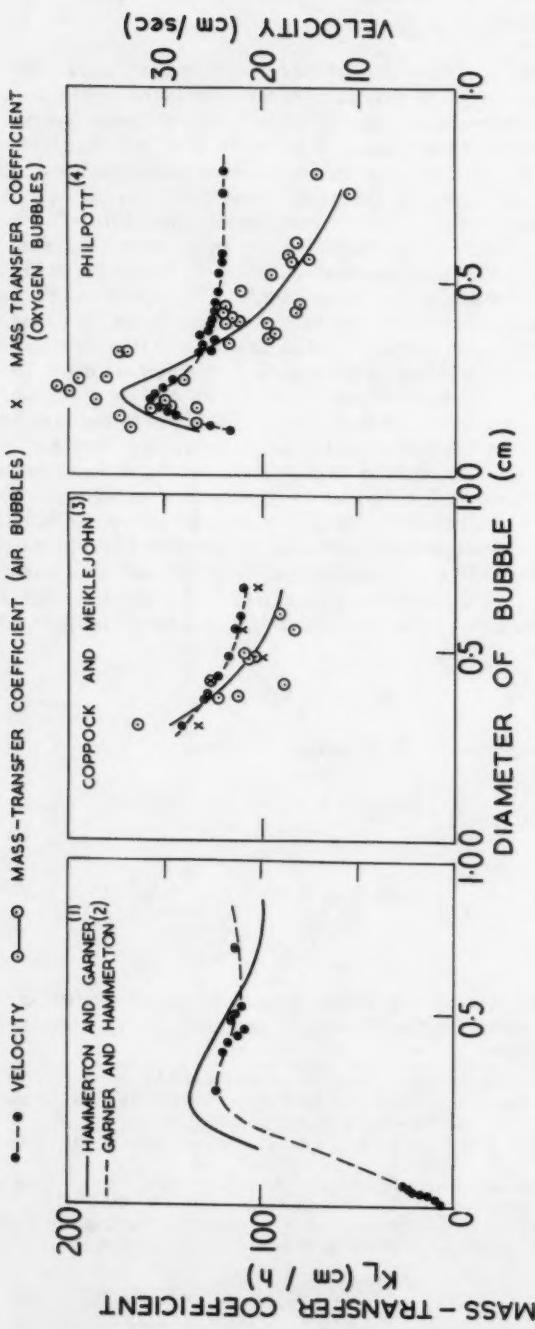


FIG. D1.—SOME PUBLISHED DATA ON THE VARIATION OF THE MASS-TRANSFER COEFFICIENT FOR OXYGEN FROM FREE-RISING BUBBLES AND THE VELOCITY OF THE BUBBLES WITH THE BUBBLE SIZE

$$K_L d_B / D_L \propto (\mu / \rho D_L)^{0.5} (d_B V_B \rho / \mu)^{0.77} \dots \dots \quad (36)$$

where ρ is the density of the liquid and d_B the bubble diameter.

This correlation is similar to that indicated by Eq. 9 for a constant depth of liquid except that the Reynolds number is raised to the power 0.77 instead of unity. It is pointed out by Calderbank that the experimental observations which were for bubbles having diameters in the range of 0.2 cm to 0.5 cm, did not reveal a dependence of K_L on velocity but this is because the velocity is substantially constant within this size range. Neither was there any apparent variation with bubble size but the range of this variation predicted by the above correlation is only $\pm 11\%$ about the mean value for the range of 0.2 cm to 0.5 cm and this may be lost in the variability of the results.

Unfortunately it seems unlikely that the foregoing correlations can be used without modification for predicting mass-transfer coefficients in liquids of the type aerated in many biological oxidation processes which frequently contain substances, for instance surface-active agents, which have a profound effect on mass transfer between air and water. It has been shown^{6,7,11} that whereas surface-active contaminants do not affect the velocity of bubbles by more than about 20% to 30%, their presence may reduce K_L for bubbles of 0.1-cm diameter or greater from values of the order of 150 to 200 cm per hr down to values of the order 10 to 45 cm per hr. The order of these values is confirmed by the results of experiments made at the Water Pollution Research Laboratory¹² in which the values of K_L for bubbles having diameters in the range of 0.15 cm to 0.25 cm, liberated from porous diffusers in water 380 cm deep, containing 5 ppm anionic detergent (expressed as sodium dioctyl sulpho succinate, a reference standard), varied between 10 and 14 cm per hr. Similar values are obtained in mixtures of sewage and activated sludge.

With regard to the effect of depth, this seems to be somewhat similar for water containing surface-active agents to that given for pure water in Eqs. 10 and 12. Thus in experiments in which water containing 5 ppm anionic detergent was aerated using a plate diffuser, the value of K_L a V varied roughly as the depth raised to a power 0.55. This implies that K_L varies inversely as the depth raised to a power, 0.45. However it seems that the effect of depth is also likely to be dependent on the bubble size, since a smaller effect was found with perforated pipes producing relatively large bubbles. This is also suggested by the data of Pasveer,¹³ the variation of the percentage oxygen absorbed with depth being very nearly linear for bubbles 0.6 cm in diameter.

It might be thought that the inclusion of the Schmidt number in Eq. 10 would take account of differences between the values of K_L in pure water and those in aqueous solutions, but here again it seems that something more would be

10 "Physical Rate Processes in Industrial Fermentation," by P. H. Calderbank, Part II, "Mass-Transfer Coefficients in Gas-Liquid Contacting with and without Mechanical Agitation," Transactions, Inst. of Chem. Engrs., Vol. 37, 1959, p. 173.

11 "Absorption of Oxygen in Bubble Aeration" by C. E. Carver, "Biological Treatment of Sewage and Industrial Wastes," ed. J. McCabe and W. W. Eckenfelder, Reinhold Pub. Co., New York, N.Y., 1956, pp. 149-171.

12 "Aeration in the Activated-Sludge Process," by A. L. Downing, Journal, Inst. of Public Health Engrs. (in press).

13 "Research on Activated Sludge, Part VI, Oxygenation of Water with Air Bubbles," by A. Pasveer, Sewage and Industrial Wastes, Vol. 27, 1955, p. 1130.

needed to bring data for water containing surface-active agents into the correlation. Possibly substitution of the surface viscosity for the bulk viscosity in the Schmidt number might go some way toward doing this.

Finally, referring to the variation of K_L a with flow of air it seems to be the general experience that the experiment (1-n) in Eq. 13 is quite close to unity for the majority of diffusion devices. For plate diffusers, 7-in. diameter porous dome diffusers, and a number of perforated pipes in water containing 5 ppm anionic detergent, values either slightly above or slightly below 1 have been obtained and for 4-in. dome diffusers¹² the value was 0.8.

W. WESLEY ECKENFELDER, JR.,¹⁴ M. ASCE.—The discussions have served to clarify the mechanism of oxygen transfer from bubble aeration. The bubble aeration correlation of Fig. 3 has been expanded to include the data of Philpott,¹⁵ Coppock and Micklejohn¹⁶ and Eckenfelder and Barnhart.¹⁷ The data of Coppock and Micklejohn were obtained by diffusion of air through circular jets from glass capillary tubing. Eckenfelder and Barnhart measured the transfer coefficient from air bubbles diffused from a nylon spinnerette, 3/4 in. in diameter with 20 holes, each 35 microns in diameter distributed over the surface. This device produced bubbles ranging from 0.12 - 0.16 cm in diameter. The expanded correlation is shown in Fig. 5.

The disagreement between Fig. 3 and the data of Philpott shown by Downing was due to the inclusion of an end correction obtained by extrapolating a line drawn through two submergence depths to zero depth. This extrapolated value was then subtracted from the overall transfer coefficient and K_L calculated from this value. When the end correction is ignored and the exponential function of depth ($h^{1/3}$) included, the data shows excellent agreement with the proposed correlation (Fig. 5).

The inclusion of the additional data expands the correlation to include Reynolds numbers as high as 2,000 with corresponding bubble diameters of 0.6 cm. The data of Quigley, Johnson and Harris¹⁸ obtained at depths less than 30 cm with R_E from 3,500 to 30,000 and bubble diameters from 1 to 4 cm exhibit a marked departure from the proposed correlation. Over the range of R_E 50 to 2,000, the bubble discharge characteristics do not appear to exert a marked effect on the relationship developed.

McKeown and Okun have indicated that portions of Pasveer's data fall into the intermediate flow range where bubble frequency is changing with gas flow. This phenomenon does not influence Eq. 10 but would exert an influence on Eq. 13. As McKeown and Okun have indicated, Eq. 13 can be modified for these conditions.

An analysis of Pasveer's data shows that the depth correction $h^{1/3}$ is in reasonably good agreement with the average reported data at depths greater than 70 cm. Ippen and Carvers data with depths greater than 68 can show a

¹⁴ Assoc. Prof., Civ. Engrg., Manhattan College, New York, N.Y.

¹⁵ "Investigations of Some of the Applications of Ultrasonic Vibrations in Public Health Engineering," by J. A. Philpott, Ph.D. Dissertation, Univ. of London, 1952.

¹⁶ P. D. Cappock and G. T. Micklejohn, Transactions, Inst. of Chem. Engrs., (br)29, 75, 1951.

¹⁷ "The Effects of Organic Substrates on the Transfer of Oxygen from Air Bubbles," by W. W. Eckenfelder and E. L. Barnhart, Presented at AIChE 42d Natl. Meeting, Atlanta, Ga., February, 1960.

¹⁸ C. J. Quigley, A. I. Johnson and B. L. Harris, Chem. Engrg. Prog., Symposium Series, 51, 16, 1955.

good correlation with $h^{1/3}$. The depth correlation deviates at depths less than 70 cm.

Shuichi Aiba has shown a linear plot of $\frac{K_L d_B}{D} h$ vs. h in order to determine the end effect by extrapolation to $h = 0$.

A better correlation can be obtained by plotting Reynolds No/Sherwood No vs depth for the average values obtained from Pasveer's and from Ippen and

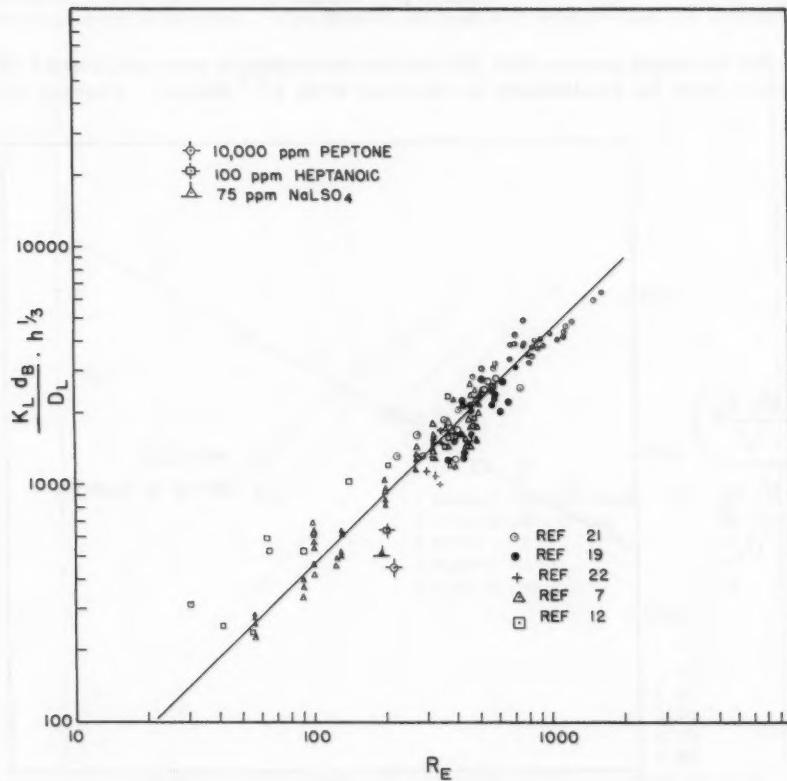


FIG. 5.—EXPANDED CORRELATION OF OXYGEN TRANSFER DATA
INCLUDING EFFECT OF SURFACE ACTIVE AGENTS

Carver's data. This correlation is shown in Fig. 6. It was observed, however, that the slope and intercept of this plot is influenced by the type of diffusion device.

Okun has indicated that an important portion of the total oxygen transfer occurs during bubble formation and release. This observation has also been made by Kountz¹⁹ while Pasveer concludes that the influence of the formation

¹⁹ R. R. Kountz, Proceedings, 9th Industrial Waste Conference, Purdue Univ., Ind., 1954.

and release of the bubble is not of great importance in the determination of K_L .

The end effect caused by the bubble bursting at the surface and surface reaeration can be corrected for, in part, by considering the term $1/h$ included in Eq. 11. When this correction is applied to the A/V ratio the shallow depths ($h < 70$ cm) correlate well in the relationship

$$\frac{K_L d_b}{D_L} = C \frac{d_b V_b}{\nu}$$

For the depth greater than 100 cm the correction is very small and a deviation from the relationship is observed when $h^{1/3}$ deleted. Pasveer also

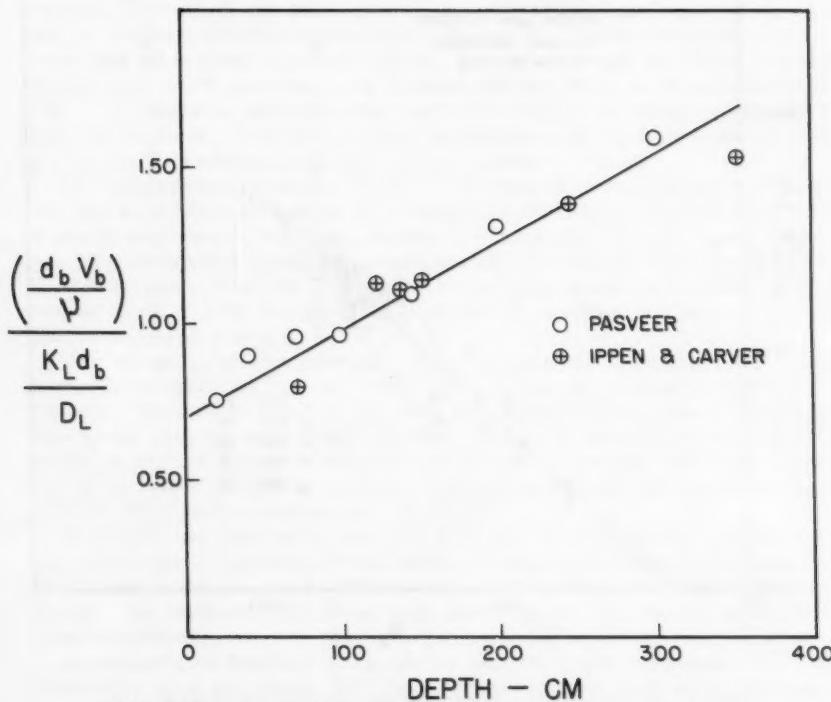


FIG. 6.—DEPTH CORRECTION FOR AVERAGE DATA OF REFERENCES 7 AND 12

points out that in deep tanks a significant change in the oxygen content of the bubble may result during rise thereby influencing the coefficient K_L . Since most aeration processes are conducted at deep depths (10 ft to 15 ft) the limitation of the depth correction $h^{1/3}$ at shallow depths should not influence design calculations.

The correlations proposed employs a bubble diameter as the diameter of an equivalent sphere. Below 0.2 cm in diameter and a corresponding R_E of

400 the bubbles closely approximate rigid spheres. At diameters greater than 0.2 cm the shape characteristics are that of a fluid ellipsoid. The exact transition from spherical to ellipsoidal is not sharply defined and may vary with characteristics of the diffusion device. Up to diameters of 0.5 - 0.6 cm employing an equivalent spherical diameter appears to conform to the proposed correlation.

In spite of some restrictions in the application of Eq. 13 as noted by the discussers this equation appears to correlate the performance of many commercial aeration devices. The data of Morgan and Bewtr²⁰ and of Dreier²¹

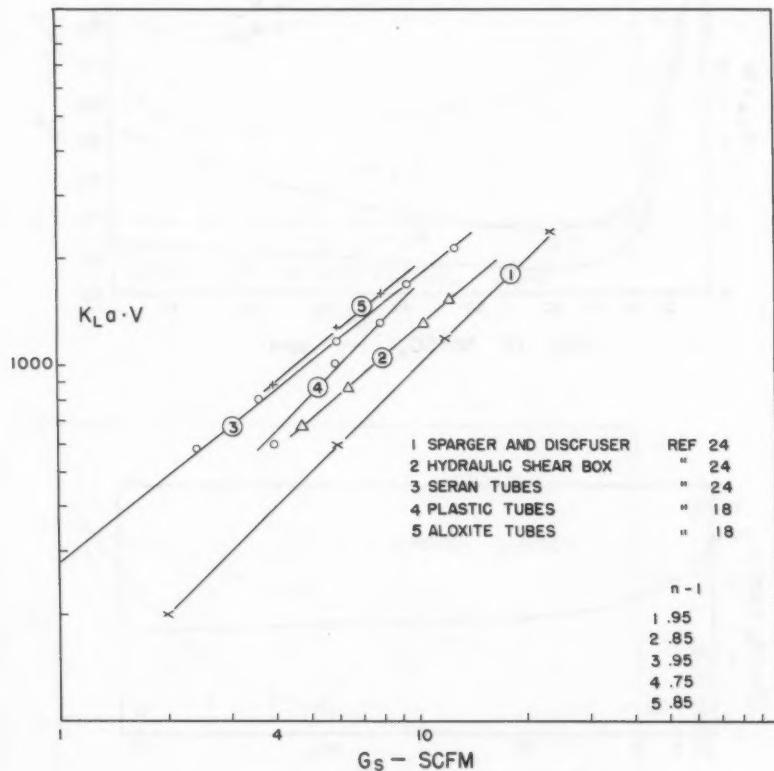


FIG. 7.—OXYGEN TRANSFER CHARACTERISTICS OF COMMERCIAL AERATION DEVICES ACCORDING TO EQUATION 13

for a constant submergence depth are plotted according to Eq. 13 and are shown in Fig. 7. The exponent (1-h) is shown on the figure for each device.

²⁰ "Diffused Air Oxygen Transfer Efficiencies," by Morgan and Bewtra, Presented at FSIWA, Dallas, Texas, October, 1959.

²¹ "Biological Treatment of Sewage and Industrial Wastes," by D. E. Dreier, Reinhold Pub. Co., New York, N.Y., 1956, p. 222.

An exponent (1-n) greater than unity occurs when the tank turbulence or other physical forces cause a splitting or redivision of the bubbles in the tank. The relationship $d_b \sim G_s^n$ does not consider such occurrences. For aeration processes in which splitting and the like do not occur the exponent (1-n) must be less than 1.0.

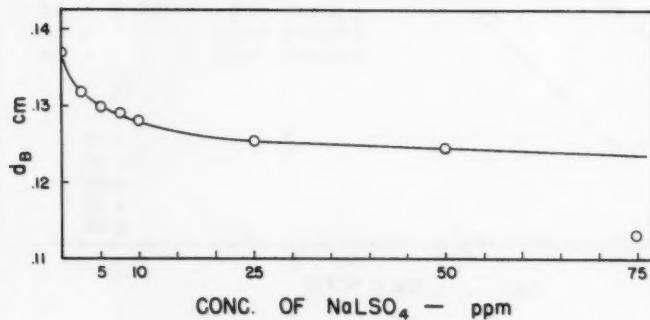
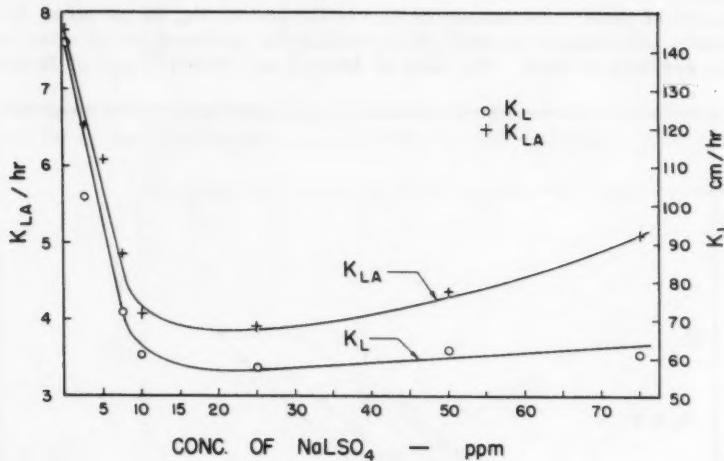


FIG. 8.—OXYGEN TRANSFER CHARACTERISTICS IN SOLUTIONS OF VARIOUS CONCENTRATIONS OF SODIUM LAURYL SULFATE

As indicated by Downing, surface active agents markedly influence the oxygen transfer characteristics of bubbles. Data for several surface active agents is included in Fig. 5 to indicate the deviation from the correlation. Correcting these data for diffusivity and surface viscosity would undoubtedly bring these points into closer agreement with the correlation.

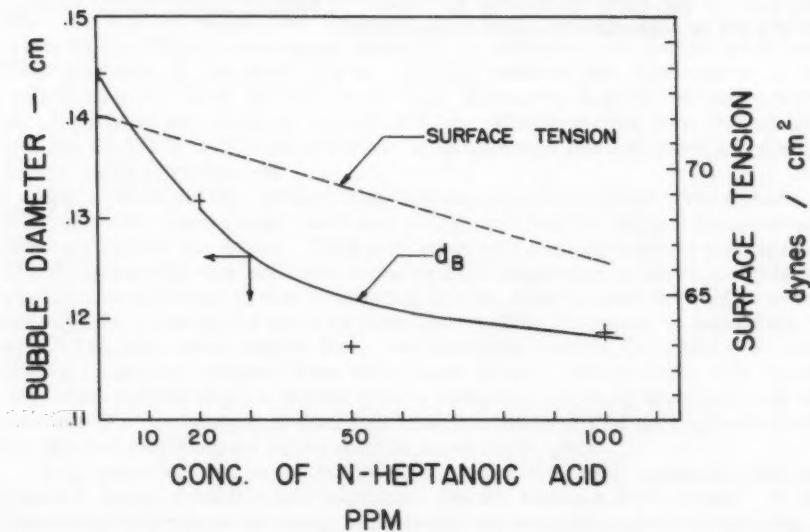
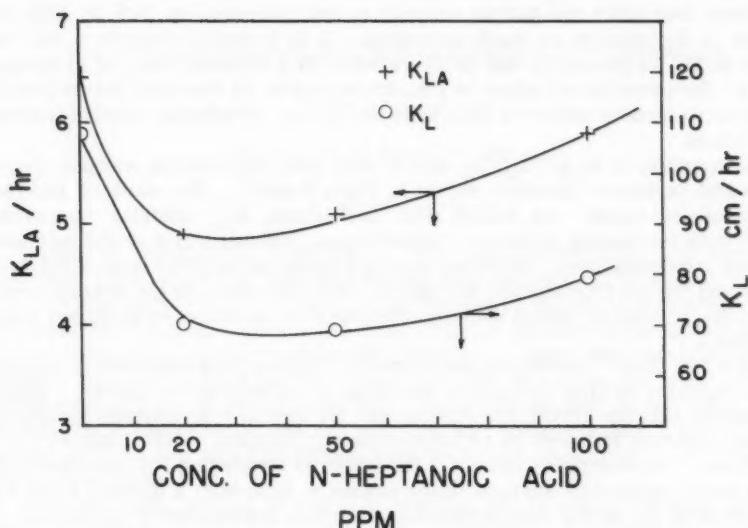


FIG. 9.—OXYGEN TRANSFER CHARACTERISTICS IN SOLUTIONS OF VARIOUS CONCENTRATIONS OF N-HEPTANOIC ACID

In bubble aeration the presence of surface active agents influence both the liquid film coefficient K_L and the interfacial area-volume ratio A/V. Downing has shown that while the bubble velocity is only affected by 20% to 30%, the changes in K_L may be as much as tenfold. It is probable therefore that the change in K_L is primarily due to the creation of a diffusion barrier at the interface. This interfacial effect is greatly dependent on the equilibrium condition at the interface which in turn depends on the turbulence characteristics of the liquid.

The variation in $K_L a$, K_L , d_B and σ with concentration for sodium lauryl sulfate and heptanoic acid are shown in Figs. 8 and 9. For each of the two substances evaluated, the liquid film coefficient, K_L , initially decreased rapidly with increasing substrate concentration, followed by a slight increase at higher concentrations. With increasing concentration, the mean bubble diameter and the surface tension decreased. The net effect on the overall coefficient, $K_L a$, was an initial decrease followed by an increase at higher concentrations.

Mancy and Okun²² conducted experiments diffusing single bubbles of oxygen from a capillary orifice in various solutions of surface active agents. Their data showed that the liquid film coefficient K_L initially decreased rapidly in low concentration followed by an approximately constant value at higher concentrations. By contrast Cullen and Davidson,²³ measuring the absorption of CO_2 in water containing surface active agents in flow over a sphere, found an initial drop in K_L at low concentrations of surface active agents followed by a rise to approach the value in pure water at higher concentrations. O'Connor²⁴ has observed this same phenomenon in surface aeration of water with surface active agents present. These observations indicate that the nature of the aeration surface markedly influences the effect of surface active agents on K_L . More work is necessary to define these effects.

²² K. H. Mancy and D. A. Okun, Progress Report, Research Grant RG-3720(C4), Natl. Inst. of Health, 1959.

²³ E. Cullen and J. F. Davidson, Chem. Engrg. Science 6,2, November, 1959.

²⁴ "Effect of Surface Active Agents on Gas Absorption," by D. J. O'Connor, Presented at AIChE 42d Natl. Meeting, Atlanta, Ga., February, 1960.

REFUSE VOLUME REDUCTION IN A SANITARY LANDFILL^a

Discussion by Desso T. Mitchell

DESSO T. MITCHELL,¹ M. ASCE.—The data, information and comments included in the paper are both stimulating and challenging, especially to those who are now using or are contemplating the use of the sanitary landfill method of refuse disposal. One of the most difficult hurdles in the task of selling this process to the public and public officials, is answering the questions as to what happens to the mass of refuse that will be buried and then, what the filled area can ultimately be used for. Efforts to explain are too often based on outright guesses or, at best, on very meager technical data. The work reported in this paper is a timely step towards filling the gap between conjecture and substantiated facts.

It would seem logical to conclude that the use to which the area occupied by a completed landfill can be put, will be affected by the stability of the fill material at any given time. This characteristic will be determined, to a large extent, by the composition of the original fill material, the initial compaction when placed and the rate and amount of decomposition over some period of time. The paper states that the initial volume reduction (for the particular material) is 25% of the original material as delivered and that an additional 25% was noted at the end of 5 yrs. On the basis of this observation, if the refuse weighed 15 to 20 lb per cu ft when delivered, it might weigh as much as 27 to 35 lb per cu ft at the end of 5 yr. Compare this with typical soil weights of 100 to 125 lb per cu ft and it is apparent that the resultant density leaves much to be desired.

The authors further report that temperature observations were made in fills variously aged from 3 days to 1 1/2 yr and that the highest temperature was observed in the latter. This may mean that temperatures in a completed landfill gradually rise and then fall with age, suggesting a corresponding increase and decrease in the composting action, until a point is reached where the organic material is more or less inert. This reasoning is supported by additional data which shows that, over the same period, the amount of combustible material dropped from an average of about 80% to 18%, dry weight. The observations did not extend over a sufficient length of time to prove the above theory or indicate at what time the maximum rate of decomposition will be reached and when all action may be expected to cease.

It is probable that most landfills, as presently being operated, will not reach a stable condition and maximum density within a 5 yr period. If this statement is accepted as being sufficiently accurate to apply to a majority of landfills, then a number of questions arise as follows:

^a November, 1959, Twenty Sixth Progress Report of the Committee on Sanitary Engineering Research of the Sanitary Engineering Division.

¹ Cons. San. Engr., The Jennings-Lawrence Co., Columbus, Ohio.

1. How long does it take for a landfill to become stable to the point where there will be no further volume reduction?
2. What is the effect of various combinations of waste substances, including garbage, on this time schedule?
3. Can the stabilization process be speeded up by the introduction or addition of some chemical or biological factor?
4. What is the effect of the average atmospheric temperature, humidity and rainfall on the rate of stabilization?
5. Will a mixture of some reasonable amount of natural soil in the fill have an accelerating effect on stabilization?

One of the advantages often attributed to the sanitary landfill method of garbage and refuse disposal is the idea of reclaiming more or less useless sites near the centers of population. There are many instances where this reasoning is justified. On the other hand, there are many cities and towns where the only available sites are valuable for present or future residential and industrial uses. Present knowledge suggests the conclusion that the landfill method of disposal in such areas may appreciably reduce land values thereby indirectly increasing disposal costs to the point where incineration may be economically justified.

Perhaps, due to the pressing urge to find a quick and low cost way to dispose of unwanted waste materials, a proper evaluation of the long range effects has been neglected. With a sufficient amount of research and resulting data as a guide, it may be found possible to operate scientifically a landfill so as to retain or improve the utility value of the land site. The work, as reported by the committee, is a step in the right direction even though much additional information is needed before a technique can be recommended that will produce an assured end result.

WASTE WATER RECLAMATION FOR GOLF COURSE IRRIGATION^a

Discussion by Garrett Sloan

GARRETT SLOAN,¹ M. ASCE.—The Department of Water and Sewers of the City of Miami, Fla., operates a high rate activated sludge sewage treatment plant on Virginia Key, an island with limited water supply. During the design of this plant, attention was given to the need for large quantities of water for chlorination, elutriation, incinerator ash disposal, and irrigation of the extensive grounds. Of these needs, plant effluent with no treatment except chlorination for slime control was decided upon for froth control on aeration tanks, elutriation, and ash disposal. For irrigation, general cleaning purposes, and cleaning of coil filters, filtration of plant effluent was selected. Approximately one half of the 65-acre plant site is now landscaped with bermuda-grass lawns and shrubbery.

A conventional rapid sand filter plant with an upflow sludge blanket treatment unit was constructed of 500,000 gpd capacity to process plant effluent for the second group of water needs previously described, and each of these requires a water free of solids because of the need of spraying water from nozzles. Typical effluent quality, before and after treatment, and after dilution with city water, is shown in Table 1.

The chlorides content of the sewage is the result of infiltration into sanitary sewers by tidal ground water along Biscayne Bay. The average chlorides content in the raw sewage and that remaining in the plant effluent has been approximately 1,500 ppm. This concentration has been found to be too high for irrigation of bermuda-grass that covers the plant site. It has been determined, through experimentation, that the treated plant effluent must be diluted with city water to obtain a chlorides concentration of 900 ppm in the summer and 800 ppm in the winter, for irrigation purposes. The amount of city water required for dilution is approximately equal to the volume of filtered sewage effluent.

Typical treatment dosage rates per million gallons are 17 lbs for sodium silicate as SiO_2 , 1,350 lbs for lime (hydrated), and 385 lbs for chlorine. Chlorine residuals vary between 1.0 and 3.0 ppm throughout the piping system around the sewage treatment plant area. The extremely high chlorine dosage is believed to render the treated water sterile, although tests have not been made to check on this. There is a tendency for the rapid sand filters to develop slime growths which would clog them, and the high dosage has been successful in keeping the sand free of such growths. This type of irrigation water has been in use for approximately three years and it has proven to be quite satisfactory.

^a November, 1959, by Robert C. Merz.

¹ Chf. Engr., Dept. of Water and Sewers, Miami, Fla.

TABLE 1.—EFFLUENT QUALITY

	Plant Effluent Before Treatment	Plant Effluent After Treatment	Treated Water plus City Water
Chlorides ^a	1,395	1,355	735
Tot. Solids ^a	3,350	3,320	1,800
Tot. Fixed Solids ^a	2,500	2,590	1,340
Tot. Susp. Solids ^a	36	24	13
Tot. Alkalinity (Mg/L Ca CO ₃)	183	226	121

^a In parts per million.

ROLE OF PRICE IN THE ALLOCATION OF WATER RESOURCES^a

Discussion by John C. Geyer

JOHN C. GEYER,³⁰ F. ASCE.—Mr. Hines' article sheds much needed light on price-cost relationships that, with political and social influences, control the allocation of water resources. The long recognized fact that water is underpriced is discussed at some length and possible remedies aimed at driving low-value uses out of the market are discussed. Increasing rate scales have been used in Latin America for some years as part of an effort to extend the benefits from a limited capital investment to as large a number of people as possible.

Underpricing of water in the United States probably grew from a feeling that water should be free for the taking, and from the fact that at the outset most prospective consumers had alternate sources, their own or a public well, which provided free water. When private enterprise undertook the development of public systems, the costs of distribution were too great for successful competition. Municipal governments then saw fit to take over most of the early systems. Thus in the water supply field, government ownership has long been accepted as proper. So accustomed is everyone to the practice that even the most conservative citizen raises no outcry against this example of socialism. In fact, it is doubtful that such a citizen could be convinced that he is supporting a socialistic enterprise.

Underpricing of water could be merely a continuation of public subsidies beyond the time of need. On the other hand it is quite possible that a public service which is predominately government supplied inevitably will be underpriced in a democracy.

The economic problems of publicly owned metropolitan water systems are more complex than might be gathered from consideration of cost-price features alone. No other utility, except perhaps sewerage service, is as expensive to enlarge, and as long lived. Enlargement or extensions of the major features of large municipal water systems are planned and built for populations 40 or 50 yr hence. The life of the works themselves is often indefinitely long. The true life of a concrete lined tunnel in solid rock might measure in geologic ages.

In many communities the burden of cost for developing expensive new sources to supply suburbia is very apt to fall on consumers living in the central sections of the city. This is because the works must be paid for before, or while, the population for which the enlargements are built migrates to, and grows in, the outside areas. This is a kind of foreign aid in which the poor, tax-ridden citizen is caught within, and must support the luxuries of his more affluent neighbor who has moved without.

^a January, 1960, by Lawrence G. Hines.

30 Chmn., Dept. of San. Engrg., The Johns Hopkins Univ., Baltimore, Md.

One might argue that the central-cities should never have allowed themselves to get into this situation. A few small communities have in fact been adamant about the matter. No water is sold beyond the city line. It is an effective way to foster annexation, but annexation brings woes in the form of demands for all the tax-supported city services many of which have long since been provided and paid for by those inside the old city line. Sewers, libraries, and better schools are examples.

In situations where the central city must, or at any rate should, serve as banker and builder of the central water collection, purification and transportation works, the problem arises as to how the city can recover its expenditure when many of the prospective consumers outside the city will not connect until after the construction bonds must be paid off. Unless a way is found, satellite communities might better be called parasite communities, for they drain the life from the corporate body onto which they are attached. When the host gets too anaemic the parasites suffer also. It is not an arrangement conducive to healthy growth.



7. 3. 2013 年 3 月 20 日，中国科学院植物研究所植物学国家重点实验室的植物分类学研究组在《植物分类学报》上发表了“中国新发现的被子植物”。

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorships indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2270 is identified as 2270(ST9) which indicates that the paper is contained in the ninth issue of the Journal of the Structural Division during 1959.

VOLUME 85 (1959)

MAY: 2014(AT2), 2015(AT2), 2016(AT2), 2017(HY5), 2018(HY5), 2019(HY5), 2020(HY5), 2021(HY5), 2022(HY5), 2023(PL2), 2024(PL2), 2025(PL2), 2020(PP1), 2027(PP1), 2028(PP1), 2029(PP1), 2030(SA3), 2031(SA3), 2032(SA3), 2033(SA3), 2034(ST5), 2035(ST5), 2036(ST5), 2037(ST5), 2038(ST5), 2039(PL2), 2040(A12)^c, 2041(PL2)^c, 2042(PP1)^c, 2043(ST5)^c, 2044(SA3)^c, 2045(HY5)^c, 2046(PP1), 2047(PP1).

JUNE: 2048(CP1), 2049(CP1), 2050(CP1), 2051(CP1), 2052(CP1), 2053(CP1), 2054(CP1), 2055(CP1), 2056(HY6), 2057(HY6), 2058(HY6), 2059(IR2), 2060(IR2), 2061(PO3), 2062(SM3), 2063(SM3), 2064(SM3), 2065(ST6), 2066(WW2), 2067(WW2), 2068(WW2), 2069(WW2), 2070(WW2), 2071(WW2), 2072(CP1)^c, 2073(IR2)^c, 2074(PO3)^c, 2075(ST6)^c, 2076(HY6)^c, 2077(SM3)^c, 2078(WW2)^c.

JULY: 2079(HY7), 2080(HY7), 2081(HY7), 2082(HY7), 2083(HY7), 2084(HY7), 2085(HY7), 2086(SA4), 2087(SA4), 2088(SA4), 2089(SA4), 2090(SA4), 2091(EM3), 2092(EM3), 2093(EM3), 2094(EM3), 2095(EM3), 2096(EM3), 2097(HY7)^c, 2098(SA4)^c, 2099(EM3)^c, 2100(AT3), 2101(AT3), 2102(AT3), 2103(AT3), 2104(AT3), 2105(AT3), 2106(AT3), 2107(AT3), 2108(AT3), 2109(AT3), 2110(AT3), 2111(AT3), 2112(AT3), 2113(AT3), 2114(AT3), 2115(AT3), 2116(AT3), 2117(AT3), 2118(AT3), 2119(AT3), 2120(AT3), 2121(AT3), 2122(AT3), 2123(AT3), 2124(AT3), 2125(AT3).

AUGUST: 2126(HY8), 2127(HY8), 2128(HY8), 2129(PO4), 2130(PO4), 2131(PO4), 2132(PO4), 2133(PO4), 2134(SM4), 2135(SM4), 2136(SM4), 2137(SM4), 2138(HY8)^c, 2139(PO4)^c, 2140(SM4)^c.

SEPTEMBER: 2141(CO2), 2142(CO2), 2143(CO2), 2144(HW3), 2145(HW3), 2146(HW3), 2147(HY9), 2148(HY9), 2149(HY9), 2150(HY9), 2151(IR3), 2152(ST7)^c, 2153(IR3), 2154(IR3), 2155(IR3), 2156(IR3), 2157(IR3), 2158(IR3), 2159(IR3), 2160(IR3), 2161(SA5), 2162(SA5), 2163(ST7), 2164(ST7), 2165(SU1), 2166(SU1), 2167(WW3), 2168(WW3), 2169(WW3), 2170(WW3), 2171(WW3), 2172(WW3), 2173(WW3), 2174(WW3), 2175(WW3), 2176(WW3), 2177(WW3), 2178(CO2)^c, 2179(IR3)^c, 2180(HW3)^c, 2181(SA5)^c, 2182(HY9)^c, 2183(SU1)^c, 2184(WW3)^c, 2185(PP2)^c, 2186(ST7)^c, 2187(PP2), 2188(PP2).

OCTOBER: 2189(AT4), 2190(AT4), 2191(AT4), 2192(AT4), 2193(AT4), 2194(EM4), 2195(EM4), 2196(EM4), 2197(EM4), 2198(EM4), 2199(EM4), 2200(HY10), 2201(HY10), 2202(HY10), 2203(PL3), 2204(PL3), 2205(PL3), 2206(PO5), 2207(PO5), 2208(PO5), 2209(PO5), 2210(SM5), 2211(SM5), 2212(SM5), 2213(SM5), 2214(SM5), 2215(SM5), 2216(SM5), 2217(SM5), 2218(ST8), 2219(ST8), 2220(EM4), 2221(ST8), 2222(ST8), 2223(ST8), 2224(HY10), 2225(HY10), 2226(PO5), 2227(PO5), 2228(PO5), 2229(ST8), 2230(EM4), 2231(EM4), 2232(A14)^c, 2233(PL3)^c, 2234(EM4)^c, 2235(HY10)^c, 2236(SM5)^c, 2237(ST8)^c, 2238(PO5)^c, 2239(ST8), 2240(PL3).

NOVEMBER: 2241(HY11), 2242(HY11), 2243(HY11), 2244(HY11), 2245(HY11), 2246(SA6), 2247(SA6), 2248(SA6), 2249(SA6), 2250(SA6), 2251(SA6), 2252(SA6), 2253(SA6), 2254(SA6), 2255(SA6), 2256(ST9), 2257(ST9), 2258(ST9), 2259(ST9), 2260(HY11), 2261(ST9)^c, 2262(ST9), 2263(HY11), 2264(ST9), 2265(HY11), 2266(SA6), 2267(SA6), 2268(SA6), 2269(HY11)^c, 2270(ST9).

DECEMBER: 2271(HY12)^c, 2272(CP2), 2273(HW4), 2274(HW4), 2275(HW4), 2276(HW4), 2277(HW4), 2278(HW4), 2279(HW4), 2280(HW4), 2281(IR4), 2282(IR4), 2283(IR4), 2284(IR4), 2285(PO6), 2286(PO6), 2287(PO6), 2288(PO6), 2289(PO6), 2290(PO6), 2291(PO6), 2292(SM6), 2293(SM6), 2294(SM6), 2295(SM6), 2296(SM6), 2297(WW4), 2298(WW4), 2299(WW4), 2300(WW4), 2301(WW4), 2302(WW4), 2303(WW4), 2304(HW4), 2305(ST10), 2306(CP2), 2307(CP2), 2308(ST10), 2309(CP2), 2310(HY12), 2311(HY12), 2312(PO6), 2313(P06), 2314(ST10), 2315(HY12), 2316(HY12), 2317(HY12), 2318(WW4), 2319(SM6), 2320(SM6), 2321(ST10), 2322(ST10), 2323(HW4)^c, 2324(CP2)^c, 2325(SM6), 2326(WW4)^c, 2327(IR4)^c, 2328(PO6)^c, 2329(ST10)^c, 2330(CP2).

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JANUARY: 2331(EM1), 2332(EM1), 2333(EM1), 2334(EM1), 2335(HY1), 2336(HY1), 2337(EM1), 2338(EM1), 2339(HY1), 2340(HY1), 2341(SA1), 2342(EM1), 2343(SA1), 2344(ST1), 2345(ST1), 2346(ST1), 2347(ST1), 2348(EM1)^c, 2349(HY1)^c, 2350(ST1), 2351(ST1), 2352(SA1)^c, 2353(ST1)^c, 2354(ST1).

FEBRUARY: 2355(CO1), 2356(CO1), 2357(CO1), 2358(CO1), 2359(CO1), 2360(CO1), 2361(PO1), 2362(HY2), 2363(ST2), 2364(HY2), 2365(SU1), 2366(HY2), 2367(SU1), 2368(SM1), 2369(HY2), 2370(SU1), 2371(HY2), 2372(PO1), 2373(SM1), 2374(HY2), 2375(PO1), 2376(HY2), 2377(CO1)^c, 2378(SU1), 2379(SU1), 2380(SU1), 2381(HY2)^c, 2382(ST2), 2383(SU1), 2384(ST2), 2385(SU1), 2386(SU1), 2387(SU1), 2388(SU1), 2389(SM1), 2390(ST2)^c, 2391(SM1)^c, 2392(PO1)^c.

MARCH: 2393(IR1), 2394(IR1), 2395(IR1), 2396(IR1), 2397(IR1), 2398(IR1), 2399(IR1), 2400(IR1), 2401(IR1), 2402(IR1), 2403(IR1), 2404(IR1), 2405(IR1), 2406(IR1), 2407(SA2), 2408(SA2), 2409(HY3), 2410(ST3), 2411(SA2), 2412(HW1), 2413(WW1), 2414(WW1), 2415(HY3), 2416(HW1), 2417(HW3), 2418(HW1)^c, 2419(WW1)^c, 2420(WW1), 2421(WW1), 2422(WW1), 2423(WW1), 2424(SA2), 2425(SA2)^c, 2426(HY3)^c, 2427(ST3)^c.

APRIL: 2428(ST4), 2429(HY4), 2430(PO2), 2431(SM2), 2432(PO2), 2433(ST4), 2434(EM2), 2435(PO2), 2436(ST4), 2437(ST4), 2438(HY4), 2439(EM2), 2440(EM2), 2441(ST4), 2442(SM2), 2443(HY4), 2444(ST4), 2445(EM2), 2446(ST4), 2447(EM2), 2448(SM2), 2449(HY4), 2450(ST4), 2451(HY4), 2452(HY4), 2453(EM2), 2454(EM2)^c, 2455(HY4)^c, 2456(HY4)^c, 2457(PO2)^c, 2458(ST4)^c, 2459(GM2)^c.

MAY: 2460(AT1), 2461(ST5), 2462(AT1), 2463(AT1), 2464(CP1), 2465(CP1), 2466(AT1), 2467(AT1), 2468(SA3), 2469(HY5), 2470(ST5), 2471(SA3), 2472(SA3), 2473(ST5), 2474(SA3), 2475(ST5), 2476(SA3), 2477(ST5), 2478(HY5), 2479(SA3), 2480(ST5), 2481(SA3), 2482(CO2), 2483(CO2), 2484(HY5), 2485(HY5), 2486(AT1)^c, 2487(CP1)^c, 2488(CO2)^c, 2489(HY5)^c, 2490(SA3)^c, 2491(ST5)^c, 2492(CP1), 2493(CO2).

c. Discussion of several papers, grouped by divisions.

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PART 2

MAY 1960 — 16

VOLUME 86

NO. SA 3

PART 2

Your attention is invited

**NEWS
OF THE
SANITARY
ENGINEERING
DIVISION
OF
ASCE**



JOURNAL OF THE SANITARY ENGINEERING DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS



DIVISION ACTIVITIES

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

NEWS

May, 1960

MINUTES
SANITARY ENGINEERING DIVISION
AMERICAN SOCIETY OF CIVIL ENGINEERS

January 5-8, 1960
Cincinnati, Ohio

Attendance: THE EXECUTIVE COMMITTEE

Messrs. Lewis Young, Chairman; John Baffa, Vice Chairman; Ray Lawrence; H. Loren Thompson, David H. Howells, Secretary; Samuel Baxter, contact member; and Don Reynolds, Assistant to the Secretary, ASCE.

1. BUDGET

Considerable dissatisfaction was expressed by members of the Executive Committee regarding the reduction in this year's SED Technical Committee budget. This action resulted in cancellation of planned meetings at the Conference of the Committees on Session Programs, Public Health Activities, and Industrial Waste Practices. In addition, attendance at the convened committee meetings was sharply curtailed.

2. TECHNICAL COMMITTEES SESSION PROGRAMS

An earlier action appointing Mr. Richard R. Kennedy to the Committee on Session Programs as a control member was confirmed. Mr. Kennedy replaces Mr. Straub.

Joint sessions with other divisions at the Phoenix and Reno Conventions were endorsed.

Members of the Executive Committee were asked to comment on a list of papers proposed for future session programs.

Note.—This paper is a part of the copyrighted Journal of the Sanitary Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. SA 3, May, 1960.

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RESEARCH

Dr. Nemerow's research proposal to Assistant Surgeon General Mark Hollis of the Public Health Service was supported in principle.

The Executive Committee met with Dr. Ingram, Chairman, Committee on Atmospheric Pollution, to discuss his plans for the establishment of an Air Pollution Research Council. Mr. Young, Mr. Howells, and Mr. Reynolds later met with the Committee on Research where this matter was reviewed further. The nature and extent of ASCE assistance to research councils appeared to be too indefinite for a decision by the Executive Committee at this time. No action will be taken until Dr. Nemerow and Dr. Ingram have developed a firm proposal based upon a clear policy statement from the Society as to its role and obligations in such an undertaking.

WATER SUPPLY ENGINEERING

The Executive Committee discussed the emerging water quality management problem and need for the Sanitary Engineering Division to establish a leadership role. The lack of the engineering profession's influence in the Senate Select Committee Hearings on Water Resources was noted. There was unanimous opinion that the existing Committee on Water Supply Engineering should serve as the framework within which the necessary additional work will be done, but that the machinery for doing this must be set up immediately.

At a subsequent joint meeting with Messers. Mitchell, Hazen, and Haney of the Water Supply Engineering Committee, Mr. Kennedy—SED representative on the Water Resources Coordinating Committee—reviewed the progress being made by the various technical divisions in their implementation of recommendations of the Horner Report.

INDUSTRIAL WASTE PRACTICES

The Executive Committee considers an early meeting of this group a necessary prerequisite to the active inauguration of its program.

This committee was encouraged to establish liaison with the National Technical Task Committee on Industrial Wastes to assist in the coordination of committee activities with other organizations working in this field.

MUNICIPAL REFUSE PRACTICES

An earlier action changing the name of the Committee on Preparation of a Manual of Practice on Incineration of Municipal Refuse to the Committee on Municipal Refuse Practices was confirmed. It was agreed that work already completed by the committee should not be lost and should be reported to the Journal of SED for publication.

3. COOPERATION WITH LOCAL SECTIONS

Mr. John J. Baffa, Vice Chairman of the Executive Committee, was appointed Chairman of the Committee on Cooperation with Local Sections.

4. COORDINATING COMMITTEE ON CIVIL DEFENSE

A slate of five SED members was prepared for use by the Division Activities Committee in the appointment of a representative from SED for the new Coordinating Committee on Civil Defense.

5. COORDINATING COMMITTEE ON MUNICIPAL PLANNING

The large variety of activities within SED and among the other technical Divisions of the Society related to municipal planning were discussed. It was the feeling of the Executive Committee that Mr. Baxter might want to bring this before the Division Activities Committee for preliminary discussions relative to the need for a Society Coordinating Committee on Municipal Planning.

6. COORDINATING COMMITTEE ON WATER RESOURCES

A motion was passed requesting the Water Resources Coordinating Committee to arrange for a presentation on behalf of the Society to the Senate Select Committee on Water Resources. This action was prompted to some extent by Mr. Schad's comments at the Conference on behalf of Senator Kerr expressing concern that insufficient testimony was being received from professional engineering groups and his invitation to ASCE for a statement on water resources.

7. ENVIRONMENTAL CONTROL AND HEALTH

The Executive Committee adopted the following draft of a resolution dealing with environmental control and health for transmittal to the Secretary of Health, Education, and Welfare, and to the Chairman of the House Appropriations Committee, by the Board of Directors.

(See next article for final text of resolution)

8. MISCELLANEOUS

NEED FOR A STANDARDS COMMITTEE IN SED

The Executive Committee discussed the advisability of establishing a committee on standards. It was the opinion of the Committee that the SED should not become involved in the preparation of standards at this time. Interest was expressed, however, in representation on committees of the American Standards Association in our area of interest. A motion was adopted asking that appropriate action be taken by Headquarters to facilitate such membership where applicable.

STUDY ON INTERCEPTION OF COMBINED SEWAGE

The study on interception of combined sewage undertaken by the late W. W. Horner was discussed and a motion passed to encourage Mr. F. E. Wisely of Horner and Shifrin to complete this work and arrange for presentation at an early SED session program and possible publication in the SED Journal.

MANUALS OF PRACTICE

Mr. Larson's letter of December 14, 1959, regarding Society policy on manuals of practice was read and agreement reached that the Division would adjust its plans accordingly.

The Executive Committee reaffirmed the position of the editing committee that the manual on Design and Construction of Sanitary and Storm Sewers be published immediately by the Society.

SED EXECUTIVE COMMITTEE ADOPTS RESOLUTIONS

(Editors Note:)

The following two resolutions were adopted by the Executive Committee and transmitted by Mr. Wisely to appropriate government officials. Both resolutions were sent to the Secretary of the Department of Health, Education and Welfare, and that pertaining to grants-in-aid was sent to Congressman Oren Harris, Chairman of the House Committee on Interstate and Foreign Commerce. Use of this method for communicating the thoughts of the Sanitary Engineering Division and the Society to policy-making officials represents a forward step.

**Resolution on Institutional Grants in Support of Sanitary
Engineering Research and Research Training.**

The engineering sciences and specialties are making increasingly strategic contributions to the fields of medicine and health. Conspicuously representative of such activity is the leadership, responsibilities, and functions of sanitary engineers—a component of the civil engineering discipline—in the rapidly expanding area of environmental health hazards, such as water pollution, air pollution and radiological health. A growing number of studies on the practice of public health, including the current Environmental Health report of the Surgeon General of the Public Health Service to the House Committee on Appropriations, have emphasized the need for increased research and a larger number of research workers involved with the problems of environmental health.

The sanitary engineering faculty and staff of civil engineering departments have benefited from the research grants mechanism of the National Institutes of Health over the past twelve years. Such support for specific studies proposed by individuals has greatly aided these engineers and scientists in their contributions to the fields of medicine and public health. Individual research grants, however, are of only nominal assistance in the training of additional recruits to the research field or in the development of the new research engineer to the point where he may also qualify for public health research grant support.

The Sanitary Engineering Division of the American Society of Civil Engineers endorses H. R. 10341, a bill to amend the Public Health Service Act to authorize grants-in-aid to universities, hospitals, laboratories, and other public or nonprofit institutions to strengthen their programs of research and research training in sciences related to health. The Society commends the support of sanitary engineering faculties through research grants and urges that the proposed support to institutions through grants for research and research training be also extended to engineering departments offering graduate training in sanitary engineering.

Resolution on Environmental Control and Health

The continuing upsurge in technological developments and the increase and concentration of our nation's population are resulting in environmental control and health problems of mounting magnitude and complexity. The sanitary and civil engineering effort needed to deal with the many hazards in man's changing environment must be substantially broadened and intensified. In addition to the traditional biological contaminants in air, water and food, major attention

must now be given to environmental contamination associated with micro-chemical substances. Man's environment including problems of water and air resources, transportation, the structures in which man lives and works, and environmental planning presents complex problems which need intensive research and study if future satisfactory development is to be achieved. A broad scale effort should be launched with emphasis on research, development of trained manpower and application of new knowledge. Full utilization should be made of Federal and State organizations as well as universities and other research institutions.

The Sanitary Engineering Division of the American Society of Civil Engineers endorses the timely request of the House Appropriations Committee that the Public Health Service make a thorough study of environmental health problems and the organization and resources needed to cope with them. The Society feels that this study is extremely important and if desired, will gladly furnish such assistance as it can.

ACTIVITIES OF SENATE SELECT COMMITTEE

With completion of the scheduled public hearings, the Senate Select Committee on National Water Resources is engaged in evaluating the testimony. All the principal federal agencies engaged in some aspect of water resources, together with several private agencies and the states, are cooperating with the Committee.

One of the most important studies, the overall water supply-demand relationships, is being developed by Resources for the Future, a privately endowed foundation. This involves taking the material received from the federal agencies, putting it in terms of estimated demands for water and then relating these demands to water supply. Each of the major river basins and regions in the United States will be treated.

Theodore M. Schad, staff director of the committee, has reported that some of the things which many of the witnesses emphasized over and over at most hearings were:

1. Increase funds and liberalization of the small watershed program.
2. Increase grants for water pollution abatement.
3. Establish federal loan program to enable cities to fully develop water supply sites.
4. Increase all phases of water resources development research.
5. Establish a natural resources council in the White House and a joint committee on natural resources in Congress.
6. Give full consideration to recreational benefits in multiple-purpose river development.
7. Give more consideration to fish and wildlife conservation in planning water resources projects.

The reports and surveys of the federal agencies are being published as Committee Prints. To date, the following prints under the general heading "Water Resources Activities in the United States" have been released.

- No. 1. Water Resources Activities (Charts and graphs)
- No. 2. Reviews of National Water Resources During the Past Fifty Years
- No. 3. National Water Resources and Problems
- No. 4. Surface Water Resources of the United States
- No. 7. Future Water Requirements for Municipal Use
- No. 9. Pollution Abatement

- No. 12. Land and Water Potentials and Future Requirements for Water
- No. 13. Estimated Water Requirements for Agricultural Purposes and Their Effects on Water Supplies
- No. 16. Flood Problems and Management in the Tennessee River Basin
- No. 19. Water Resources of Alaska
- No. 20. Water Resources of Hawaii
- No. 23. Evaporation Reduction and Seepage Control
- No. 25. River Forecasting and Hydrometeorological Analysis
- No. 26. Saline Water Conversion
- No. 27. Application and Effects of Nuclear Energy

In addition, transcripts of the hearings before the Committee have been released as follows:

- Part 1 - Bismarck, North Dakota-October 7, 1959
- Part 2 - Laramie, Wyoming-October 8, 1959
- Part 3 - Billings, Montana-October 9, 1959
Missoula, Montana-October 12, 1959
- Part 4 - Boise, Idaho-October 13, 1959
- Part 5 - Sacramento, California-October 15, 1959
Los Angeles, California-October 16, 1959
- Part 6 - Huron, South Dakota-October 27, 1959
Sioux Falls, South Dakota-October 28, 1959
- Part 7 - Detroit, Michigan-October 29, 1959
- Part 8 - Philadelphia, Pennsylvania-October 30, 1959
- Part 9 - Topeka, Kansas-November 18, 1959
- Part 10- Des Moines, Iowa-November 19, 1959
- Part 11- Denver, Colorado-November 20, 1959
- Part 12- Albuquerque, New Mexico-November 23, 1959
- Part 13- Salt Lake City, Utah-November 24, 1959
- Part 14- Fort Smith, Arkansas-November 28, 1959

* * *

SANITARY ENGINEERING EDUCATION

U. S. PUBLIC HEALTH SERVICE SUMMER TRAINING INSTITUTE

The Training Program of the Robert A. Taft Sanitary Engineering Center will conduct a group of courses in the classrooms and laboratories of the Florida State University, Tallahassee, Florida, during the period July 10-15, 1960. The objective of these courses is to provide an opportunity for professional personnel of State and local agencies, industries, and university staffs located in the southeastern section of the country to attend the highly specialized courses given normally in Cincinnati, Ohio, only.

The courses to be presented in the Summer Training Institute are as follows:

Atmospheric Particulate Sampling

Water Quality Studies

Environmental Radiation Surveillance

Further information may be obtained from Mr. Howard W. Chapman, Regional Engineer, PHS, DHEW, Region IV, Room 164, 50 Seventh Street, N. E., Atlanta 23, Georgia.

SUMMER FIELD TRAINING INSTITUTE FOR ENGINEERS AND SANITARIANS

This will be the tenth consecutive summer in which the Oklahoma State Health Department, the U. S. Public Health Service, and the University of Oklahoma will jointly sponsor field training for American and International public health workers during the period June 6-August 5, 1960.

The University of Oklahoma Department of Sanitary Science and Public Health offers, to qualified students, 5 to 8 hours credit in Course 250, Public Health Practices (graduate or undergraduate), for satisfactory completion of this training course. Students enrolling for credit will be required to pay the regular tuition. No fees are required for other students taking the field training.

The purpose of this field training is to provide students with a practical field training through a "learn-by-doing" technique, and to give them a broad acquaintance with public health practice.

Each of the eight weeks will consist of supervised field work and laboratory practice, together with group discussions on the field work. In general, the procedure will be to discuss briefly the basic public health aspects, principles, and practices of each phase of local health sanitation, with major attention being devoted to sanitation problems. These problems will then be carried out, insofar as possible, as an integral part of the regular sanitation program of the area.

Interested Engineers and Sanitarians can obtain further information and applications from George W. Reid, Coordinator, Department of Sanitary Science and Public Health, University of Oklahoma, Norman, Oklahoma.

SEC TRAINING COURSES FOR FY 1961

The following training courses have been tentatively scheduled for the period July 1, 1960-June 30, 1961 at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Since this is a preliminary listing, anyone desiring further information should contact H. P. Kramer, Chief, Training Branch, Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

July 11-22, 1960

ADVANCED TRAINING FOR ENGINEERS AND SCIENTISTS
FROM FOREIGN COUNTRIES (47S)

August 8-12, 1960

RADIOLOGICAL HEALTH FOR NURSES (78R)

August 15-19, 1960

RECENT DEVELOPMENTS IN WATER BACTERIOLOGY (4W)

September 12-23, 1960

RADIONUCLIDES IN FOOD (59MR)

September 19-30, 1960

ATMOSPHERIC AND SOURCE SAMPLING (52A)

October 3-14, 1960

BASIC RADIOLOGICAL HEALTH (6R)

October 17-21, 1960

RADIONUCLIDE PROTECTION (60R)

1960-16--8

SA 3

May, 1960

October 17-21, 1960
RADIOLOGICAL HEALTH FOR X-RAY TECHNICIANS (49R)

October 24-28, 1960
X-RAY PROTECTION (61R)

October 24-November 4, 1960
PLANKTON ANALYSIS (19W)

November 7-11, 1960
CONTROL OF PARTICULATE EMISSIONS (62A)

November 7-11, 1960
RADIOACTIVE POLLUTANTS IN WATER (20WR)

November 14-18, 1960
CONTROL OF GASEOUS EMISSIONS (63A)

November 14-18, 1960
RADIONUCLIDES IN WATER (65WR)

November 28-December 9, 1960
CHEMICAL ANALYSES FOR WATER QUALITY (3W)

November 28-December 9, 1960
MEDICAL ASPECTS OF RADIOLOGICAL HEALTH (50R)

December 12-16, 1960
MEDICAL AND BIOLOGICAL ASPECTS OF AIR POLLUTION (68A)

December 12-16, 1960
DETERMINATION OF ANTIBIOTIC AND PESTICIDE RESIDUES
IN MILK (72M)

January 9-20, 1961
ORIENTATION IN RADIOLOGICAL HEALTH (64R)

January 9-20, 1961
INDUSTRIAL WASTES TREATMENT (73W)

January 23-27, 1961
RECENT DEVELOPMENTS IN WATER BACTERIOLOGY (4W)

January 23-February 3, 1961
BASIC RADIOLOGICAL HEALTH (6R)

January 30-February 3, 1961
MICROBIOLOGICAL AND CHEMICAL EXAMINATION OF MILK
AND DAIRY PRODUCTS (2M)

February 6-10, 1961
RADIOACTIVE POLLUTANTS IN AIR (39AR)

February 6-10, 1961
LABORATORY METHODS FOR PREVENTION AND CONTROL OF
FOOD-BORNE DISEASE (9M)

February 13-17, 1961
RADIOACTIVE POLLUTANTS IN WATER (20WR)

February 13-24, 1961
MICROSCOPIC ANALYSES OF ATMOSPHERIC PARTICULATES (71A)

ASCE

Sanitary Engineering Division

1960-16--9

February 20-24, 1961

RADIOMUCLIDES IN WATER (65WR)

February 27-March 10, 1961

WATER QUALITY MANAGEMENT—SANITARY ENGINEERING ASPECTS
(1W)

March 6-17, 1961

COMMUNITY AIR POLLUTION (53A)

March 13-24, 1961

BASIC RADIOLOGICAL HEALTH (6R)

March 20-24, 1961

ANALYSIS OF ATMOSPHERIC INORGANICS (54A)

March 27-31, 1961

ANALYSIS OF ATMOSPHERIC ORGANICS (55A)

March 27-April 7, 1961

SANITARY ENGINEERING ASPECTS OF NUCLEAR ENERGY (35R)

May 1-10, 1961

REACTOR ENVIRONMENTAL HEALTH PROBLEMS (36R)

May 1-12, 1961

ATMOSPHERIC AND SOURCE SAMPLING (52A)

May 8-19, 1961

ORGANIC INDUSTRIAL WASTES CHARACTERIZATION (57W)

May 15-19, 1961

CONTROL OF PARTICULATE EMISSIONS (62A)

May 22-26, 1961

INORGANIC INDUSTRIAL WASTES CHARACTERIZATION (10W)

May 22-26, 1961

CONTROL OF GASEOUS EMISSIONS (63A)

May 29-June 2, 1961

SHELLFISH SANITATION (44M)

June 5-16, 1961

ADVANCED TRAINING FOR SANITARY ENGINEER RESERVE OFFICERS

June 19-30, 1961

AQUATIC BIOLOGY FOR ENGINEERS (12W)

June 19-30, 1961

RADIOMUCLIDES IN FOOD (59MR)

RENSSELAER SETS UP ENVIRONMENT ENGINEERING CURRICULUM

Rensselaer Polytechnic Institute has, after three years of study by a campus-wide faculty committee, established a new curriculum leading to the degrees of Bachelor of Science in Environmental Engineering and Master of Science in Environmental Engineering. The objective of the new curriculum is:

To provide for an educational experience based upon a strong background

in science. This will prepare the individual for service in the engineering aspects of the modern practice of control of the environment as a whole.

To prepare the student for effective work on the graduate level in one or more of the specific areas of interest. A greater depth of study within a particular area of special interest is also made possible by the choice of electives.

Required courses and suggested electives are shown in the current Rensselaer Polytechnic Institute under-graduate catalogue. Further information may be obtained from Professor E. J. Kilcawley, Head Division of Environmental Engineering, R. P. I., Troy, New York.

* * *

Water Supply & Pollution Control

Conference of

STATE AND INTERSTATE WATER POLLUTION CONTROL ADMINISTRATORS Chicago, Illinois January 26-27, 1960

CONCLUSIONS AND RECOMMENDATIONS

FEDERAL LEGISLATION

1. H.R. 3610: The Conference went on record in recommending that the amount of maximum grant be increased from \$250,000 to \$500,000 and that the annual appropriation be increased to \$100 million and with the total authorization for appropriations under the act be increased to one billion dollars.

The Conference went on record as favoring Senate version of Section 6 in that sums allotted to States which are not obligated within six months following the end of the fiscal year for which they were allotted, such funds be re-allocated.

Note: The President vetoed this bill, and his veto was sustained.

2. Appropriations for F.Y. 1961: Conference recommended that the appropriation for construction grants for F.Y. 1961 be the maximum (\$50,000,000) that is authorized by law.
3. Extension of Section 5. P.L. 660: The Conference recommends the extension of Section 5, P.L. 660, and an increase in the appropriation under the Section from \$3 million to \$5 million, and that the program grants to State and interstate water pollution agencies be administered under the same techniques as the administration of other Public Health Service grant funds.
4. National Conference on W.P.C.: It was the consensus of the Conference that as an aid to State programs we should seriously consider such a conference. Two things would be of paramount importance in considering such a conference. They are (1) adequate financing, and (2) meticulous planning.
5. H.R. 8494: Conference was opposed to broadening the scope of the act to include all navigable waters. It was not opposed to some broadening of the act to cover those situations where pollution abatement is not being effected.

6. **H.J. Res. 522:** The Conference concurred in the items contained in H.J.R. 522 (expansion of certain water pollution research) and recommends that adequate appropriations be made to permit implementation of the studies proposed.

STATE - FEDERAL RELATIONS ON RESEARCH, SPECIAL STUDIES, AND INVESTIGATIONS

7. The Conference recommends that increased appropriations should be made to the U. S. Public Health Service to support research and special studies related to water pollution control to meet the increasing demands for answers to the many complex problems which are existent in this field. More assistance should be given to States in the form of advice and guidance in solving many pollutional problems. This is urgently needed and can only be developed and given when supported by research and special studies carried on in a much more intense form than has prevailed in the past.

The U. S. Public Health Service is the logical agency to carry on an adequate program of research and special studies in the water pollution field as the basis for assisting State and Interstate water pollution control agencies in the administration of State and Interstate pollution control progress. Accordingly, adequate funds for the purpose should be made to the P.H.S. to enable it to discharge its responsibility in this research and special studies field.

It is recommended that the present level of expenditures for research and special studies in the water pollution control field be tripled next year to a level of approximately \$2,000,000 and that it be increased thereafter as the needs warrant.

8. It is recommended that the Public Health Service set up necessary machinery within its organization to provide for more prompt printing and distribution of technical reports. It is also recommended the P.H.S. establish necessary organization to serve as a clearing house for all technical information in the water pollution control field with full distribution to all States and associated organizations.

Distribution to the field of the summary of research presently under way should be continued.

9. It is concluded that there are many areas needing research and it is recommended the Executive Committee of the Conference appoint a Research Committee to work with the P.H.S. to develop mechanics whereby research and special studies needs may be made known to research organization.

10. State and Interstate water pollution control agencies have a definite responsibility and need for carrying on applied research in relation to many specific water pollution problems. Accordingly, strong efforts should be made to provide in addition to regulatory funds, reasonable sums in the budgets for these State and Interstate agencies to enable them to engage in such research work. It is suggested that all agencies interested in water pollution control do what they can to impress on the various state governments the need for provision in the budgets of State and Interstate agencies reasonable sums of monies to enable them to carry on much needed research of an applied nature and related to the solution of specific problems. In connection with this matter it is also recommended that consideration

be given to a Federal-aid program to support research and special studies related to specific pollutional problems to be carried on by State and Interstate agencies under a matching fund arrangement.

11. This Conference recognized the fact that the necessity of water re-use, water supplementation, and water conservation is current in some areas of the Nation and foresees numerous complex problems involving water quality presented by such practices. It is recommended, therefore, that water pollution control agencies consider water conservation and water supplementation programs as legitimate areas of official interest and encourage necessary research and studies in this field.

ROLE OF STATE, INTERSTATE, AND FEDERAL WATER POLLUTION CONTROL AGENCIES IN ENFORCEMENT ACTIVITY:

12. The Conference made the following conclusions:
 - A. That the States have primary responsibility in pollution control and while substantial accomplishments have and are being made, some present State laws may be inadequate with respect to enforcement.
 - B. Where Interstate compacts are in operation, they have proven to be an effective mechanism in the coordination and promotion of regional programs.
 - C. That the Federal government under P.L. 660 has an important role with respect to the enforcement of Interstate water pollution control, and that it has proven to be an effective element in the progress of the over-all program.
 - D. That Federal government authority in relation to enforcement should be exercised only after the other enforcement procedures have failed, and then only in cooperation with the States concerned.
13. The following recommendations were made by the Conference:
 - A. That States examine their laws, rules, regulations, and administrative procedures with a view toward further improving their program.
 - B. That States take full advantage of aids available through the Federal government as a further means of expediting their programs.

RELATIONSHIP OF WATER POLLUTION CONTROL TO OVERALL PROGRAMS FOR WATER RESOURCE MANAGEMENT, INCLUDING THE RELATIONSHIP OF WATER POLLUTION CONTROL ADMINISTRATORS TO THE INTERSTATE CONFERENCE ON WATER PROBLEMS:

14. Inasmuch as water quality and water pollution control and important aspects of water resource management, it is recommended that the water pollution control administrators become more prominently identified with the Interstate Conference on Water Problems.

RECRUITMENT, TRAINING AND COMPENSATION OF PERSONNEL, INCLUDING ADVANCE TRAINING FOR ADMINISTRATIVE PERSONNEL:

15. Compensation schedules in most States are quite unrealistic. They need revision upward in order to maintain a high level of professional and

management competency in the increasingly complex field of water pollution control programs.

BASIC DATA PROGRAMS AND PERFORMANCE STANDARDS

16. Correlation of the collection and evaluation of information:
 - A. From State, Interstate and Federal Basic data programs:
 1. This Conference recognizes that comprehensive water quality basic data is essential to the operation of State and Interstate water pollution control programs and recommends that:
 - a. Water quality basic data networks be developed and extended by State and Interstate agencies.
 - b. Municipalities and industries be encouraged to collect basic data on streams both above and below waste discharges as a part of their responsibility in the overall water quality control program.
 - c. State and Interstate control agencies consider the development or expansion of split sampling procedures using municipal and industrial laboratories for analyses as well as their own.
 - d. Data be processed in a uniform manner by State, Interstate and Federal agencies to permit more effective use of the information available.
 2. This Conference endorses the operation of the National Water Quality Network and recommends its expansion in accordance with current plans, cooperating with State and Interstate agencies.
 3. This Conference recommends that there be continued coordination of the activities of the U. S. Geological Survey, the U. S. Public Health Service and other Federal agencies engaged in water quality basic data survey work.
 4. This Conference recognizes that the lack of adequate manpower and facilities has caused the collection and analyses of samples collected in water quality survey programs to become a problem in some areas, and recommends that a program of research and development for instrumentation and automation for all conditions of climate and stream flow be undertaken not only to extend present manpower but to enable agencies to carry on a more adequate and comprehensive program. U. S. Public Health Service assistance for service and development programs would be of benefit.
 - B. Operation and performance of waste treatment facilities:
Operation and consequent proper performance of waste treatment facilities have not always kept pace with progress in construction of such waste treatment facilities.
This Conference recommends that Water Pollution Control agencies exert all possible effort to develop properly qualified operators, and urge owners of waste treatment facilities to employ only competent, adequately compensated personnel.

DEVELOPMENT OF CRITERIA FOR MEASURING PROGRESS OR LACK OF PROGRESS IN POLLUTION CONTROL PROGRAMS:

17. The following conclusions were reached:
 - A. That we know of no universal parameters which have been used for this purpose and which can be properly applied to measure progress in

pollution control. It is the opinion of this Conference that there is sufficient need for such a parameter to justify continued and extensive exploration of the subject.

- B. Parameters which have been used by individual States and groups of States with the same general stream pollution conditions have merit and deserve consideration for specific areas.
- C. Until better parameters are developed it is recommended that professional evaluation by the respective State water pollution control administrators be utilized to measure progress in water pollution control.
- D. The Conference recommends that the P.H.S. be requested to develop suggested criteria for measuring progress of pollution control programs and report to the next conference of water pollution control administrators.

WATER

comes in oceans, rivers, lakes, wells, drops,
buckets, pitchers and glasses.

it quenches thirsts, cooks food, puts out fires,
makes coffee and brushes teeth.

it spins mills, runs electro-plants,
cools motors and powers factories.

it spawns fish, sprinkles lawns, floats boats,
washes children and grows flowers.

it sustains and nurtures.

it bends if you give it purpose.

it reshapes itself if you give it reason.

it is needed, wanted, feared,
praised and prayed for.

it is at the heart of all life.

it is in the arteries of all industry.

it is as close to us as skin
but as taken for granted as sky.

the end of water seems unbelievable.

if it is not on the horizon, it is just over it.

if it is not within sight, it is just 'round the bend.

if it is not in the glass, it is just in the spigot.

. . . this is the grand mirage . . .

the self-delusion that prevails

though the wells run low

and the streams go dry

and the water slips away.

we know water,
we know its ways.
we've learned its habits.
we've pulled it out of swamplands,
pushed it over mountains,
pumped it into deserts,
tunneled it through granite,
and rescued it from pollution.

above all else,
we know the need for it.
that is why,
for 130 years,
we've developed new uses for,
powered new factories with,
diverted the courses of
and jealously stood guard over
water.

The above appeared in a Fairbanks, Morse advertisement in a recent issue of Business Week. It is reproduced through the courtesy of Mr. Robert W. Kerr, President of Fairbanks, Morse & Co., Chicago, Illinois.

WPC ADVISORY BOARD MEETS JANUARY 18-19

The following resolutions were adopted by the President's Water Pollution Control Advisory Board at its meeting in Washington, D. C., January 18-19, 1960.

1. CONSTRUCTION GRANTS

The Water Pollution Control Advisory Board, after careful analysis of the construction grants program for municipal waste treatment works to control water pollution, as authorized by Section 6 of the Federal Water Pollution Control Act, believes that these grants have significantly stimulated and increased construction of needed facilities. At the same time there has been no slow down in the rate of construction of such treatment works financed entirely by nonfederal funds.

The Board further believes to safeguard public health and other legitimate water uses, that additional incentives are needed to meet the backlog of municipal waste treatment facility construction.

In view of the fact that both the Senate and House of Representatives of the Congress of the United States have passed bills authorizing the increase of such construction grant funds and in view of the possibility that a bill to accomplish this result may soon be passed by the Congress and sent to the President for signature, the Board urges the Secretary of Health, Education, and Welfare to support approval of the bill.

2. BUDGET IDENTIFICATION

In view of increased public and Congressional awareness and interest in the Federal Water Pollution Control Program, and their consequent interest in appropriations for such program, the Board believes that the budget should contain a separate and distinct item for water pollution control activities so as to be readily identifiable at all stages of the budget and appropriation process.

3. FEDERAL AND OTHER PUBLIC INSTALLATIONS

The Board urges all Federal and other public installations having waste disposal problems to set an example to the rest of the country by better cooperation with State water pollution control agencies and the Public Health Service in installing needed waste treatment facilities.

4. INTERSTATE ENFORCEMENT

The Board recommends the strengthening of the enforcement provisions of the Federal Water Pollution Control Act in order to provide a more equitable mechanism for the preservation and improvement of the quality of this Nation's waters. The Act should be amended so that sources of pollution will not be exempt from the provisions of the Act merely because of fortuitous geographic location.

The Board recommends extending Federal Government jurisdiction to cover pollution of all interstate and navigable waters, provided that State concurrence is obtained before the Federal Government enters an intra-state pollution situation.

5. RESEARCH NEEDS

In view of the increased discharges of new products and wastes, as well as problems caused by population and industrial growths and increased urbanization, the Board recommends the establishment of additional co-operative State-Public Health Service basic data stations. A sufficient number should be established to provide information on the quality of our Nation's water so as to enable States, localities, industries, and the Federal Government to protect the public health and conserve such waters for public water supplies, propagation of fish and aquatic life and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses.

6. FEDERAL INSTALLATIONS

The Board recommends that the enforcement provisions of the Federal Water Pollution Control Act be expanded to include coverage of discharges from Federal installations. The Board believes that this suggested procedure will, in most cases, provide the necessary stimulation to assure the installation of appropriate waste treatment measures by Federal installations.

ARTIFICIAL RECHARGE OF GROUND WATER SUCCEEDS AT WALLA WALLA, WASHINGTON

Experimental "artificial recharge" of water-bearing rocks a few miles east of Walla, Walla, Wash., has shown the practicability of using this means of backstopping the municipal water supply.

About 70-acre feet of creek water was injected, at an average rate of 650 gallons per minute, into an 1,169-foot municipal well penetrating the water-bearing rock formation known to geologists as the Columbia River basalt. The study area is one in which the structure of the rocks limits natural recharge, and there has been concern over the persistent lowering of water level caused by years of pumping.

The chemical and bacteriological quality of the injected water was excellent, and it contained only 2 parts per million of suspended sediment. Although the quantity of water injected was small, the experiment was successful

in showing that artificial recharge of basalt on a continuing basis is feasible.

Some reduction in well yield occurred as a result of the recharging experiment. However, it is believed that the loss does not represent permanent deterioration of the well. With a carefully controlled schedule of alternating recharge and pumping, it is believed that as much as 1,000 gpm can be injected into the well during the 9 months of the year when creek water is available.

The report is to be reproduced for distribution by the Washington Department of Conservation, Olympia, Washington.

TWO STATES ENTER COOPERATIVE SALINE WATER RESEARCH AGREEMENTS

The Department of the Interior recently announced the signing of separate cooperative agreements with the States of South Dakota and North Carolina, providing for mutual assistance in the study of saline water conversion problems.

The agreements provide for general assistance and exchange of information between the individual States and the Department's Office of Saline Water on development of improved saline water conversion processes and their actual potential application. The Department has previously announced similar agreements with the States of California, New Mexico, Arizona, Florida, and Texas.

SOUTH DAKOTA AND NEW MEXICO TO GET BRACKISH WATER CONVERSION DEMONSTRATION PLANTS

Secretary of the Interior Fred A. Seaton recently announced selection of Webster, South Dakota and Roswell, New Mexico as sites for the two brackish water conversion demonstration plants authorized by Public Law 85-883.

The plant to be located at Webster, South Dakota, will utilize an electro-dialysis process designed to produce fresh water at the anticipated rate of 250,000 gallons per day. A forced-circulation vapor compression distillation process, which will be designed to produce fresh water at the rate of at least 250,000 gallons per day will be erected in Roswell, New Mexico.

Both cities have offered considerable assistance to help defray the Federal investment in these plants. Each city has agreed to provide the land required for the plant, purchase the product water, deliver the brackish water to the conversion plant, and dispose of the brine. The State of New Mexico has also appropriated \$100,000 to provide up to 10 percent of the cost of the Roswell plant.

BLAW-KNOX AWARDED CONTRACT FOR 35,000 GALLON PER DAY PILOT PLANT TO TEST NEW SALINE WATER CONVERSION FREEZING PROCESS

The Department of the Interior has awarded the Blaw-Knox Co. of Pittsburgh, Pennsylvania, a \$141,430 contract for a pilot plant to convert sea water to fresh using a direct-freezing process. The pilot plant, designed to produce 35,000 gallons of fresh water per day, is based on the use of a secondary refrigerant. The plant will be erected at a sea coast location at a yet unselected site.

The process was initially developed by Prof. H. F. Wiegandt of Cornell University. Later developments have been carried out concurrently by the

Blaw-Knox Company and Prof. Wiegandt. All laboratory and small scale pilot work, which has been conducted to provide the necessary data on the various phases of the process to determine its technical feasibility and economic potential has been carried out under contract with the Office of Saline Water.

Converting sea water to fresh by freezing has several inherent advantages over conventional distillation processes. For example, the lesser tendency toward scaling and corrosion because of the low operating temperatures involved, and more important perhaps, the lower energy requirement to freeze sea water as compared to the energy required for the evaporation of sea water. An ice crystal is pure water, but when sea water is frozen the salt is trapped in the interstices of the ice crystals. To make a freezing process a commercial reality a low-cost method of separating the two must be developed.

The desalinization method, to be known as the Cornell Process, is based on the flash evaporation of a volatile and immiscible hydrocarbon, such as butane, in direct contact with sea water which will cause part of the sea water to freeze. The resulting ice-slush that is formed consists of a mixture of pure ice crystals and brine. The ice crystals are washed free of adhering brine and then melted to produce water by the heat of condensation of the refrigerant.

This is the second freezing process pilot plant to be built under contract with the Office of Saline Water. The Carrier Corporation of Syracuse, New York, began operating a 15,000 gallon per day vacuum-process pilot plant in October 1959.

NEW COTTON TEXTILE INDUSTRIAL WASTE GUIDE

A new Industrial Waste Guide to the cotton textile industry has been published by the Public Health Service. This is the fifth in a series of Guides prepared by the National Technical Task Committee on Industrial Wastes, and was written by the National Stream Sanitation Committee of the American Association of Textile Chemists and Colorists under the direction of R. Hobart Souther.

This Industrial Waste Guide to the Cotton Textile Industry is intended primarily to assist the operators and managers of cotton textile processing plants to utilize, reduce, and otherwise suitably dispose of their waste waters. It will also be useful in informing consultants and personnel of regulatory agencies of the sources and pollutational characteristics of cotton textile wastes and the status of developments in waste treatment.

This Guide has been published as Public Health Service Publication No. 677, and is available from the Supt. of Document, Government Printing Office, Washington 25, D. C. for 25 cents.

REPORT OF OPERATION OF SALINE WATER CONVERSION PILOT PLANT AT WRIGHTSVILLE BEACH, NORTH CAROLINA, NOW AVAILABLE

The Office of Saline Water Research and Development Progress Report No. 26, "Operation of Pilot Plant LTV Evaporator at Wrightsville Beach, North Carolina," has been published by the Office of Technical Services and is for sale by the U. S. Department of Commerce, Washington, D. C. The price is \$2.75 and orders should specify PB 161290.

The report was prepared by W. L. Badger Associates, Inc., of Ann Arbor, Michigan. It contains detailed information of the data obtained from experimental work conducted from November 1957 through May 31, 1959. The primary objective in the development of the long-tube vertical multiple effect evaporator for saline water conversion is to minimize the ultimate cost of producing potable water by (1) preventing formation of scale on heating surfaces, and (2) minimizing corrosion to permit use of inexpensive materials of construction.

FLORIDA OIL POLLUTION CONDITIONS

The American Petroleum Institute recently released a report by John V. Dennis entitled "Oil Pollution Conditions of the Florida East Coast". This study was a recheck of the area studied in a previous report published in May 1959. The report concludes that oil pollution "was most acute in 1952 and 1953, and that it has steadily declined in security since then." Information concerning the availability of the report may be obtained from the American Petroleum Institute, Division of Transportation, 1625 K Street, N. W., Washington 6, D. C.

SEC WATER QUALITY SYMPOSIUM DATES CHANGED

The Public Health Service symposium on water quality measurement and instrumentation, to be held at the Sanitary Engineering Center at Cincinnati, Ohio on August 23, 24, and 25, 1960 has been rescheduled for August 29, 30, and 31. Anyone wishing to receive the agenda and other announcements may write to The Director, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

POLLUTION CONTROL BILL DIES AS HOUSE SUSTAINS VETO

H. R. 3610, the bill which would have increased grants to municipalities for the construction of sewage treatment plants, was killed February 25 when the House failed to override the President's veto.

Tally on the bill was 249 ayes and 157 noes, 22 votes short of the two-thirds majority necessary to override.

Failure of H.R. 3610 to become law, however, does not affect the Federal Water Pollution Control Act of 1956, which it would have amended. The Act, Public Law 660, remains in force and authorizes appropriations of \$50.00 million per year and a ceiling of \$250,000 for individual projects. H.R. 3610, as originally passed by Congress, would have raised the authorizations to \$90 million per year to a total of \$900 million with a \$450,000 ceiling for projects.

* * *

Air Pollution

BLOW-BY DEVICE EVALUATED IN CONGRESSIONAL HEARINGS

Hearings were held on February 23 and 24, 1960, by the Subcommittee on Health and Safety of the House Interstate and Foreign Commerce Committee, for purposes of examining the potential usefulness of the recently publicized

blow-by device—an inexpensive, simple means of eliminating pollutants from automotive crankcase ventilating systems. A spokesman for the Automobile Manufacturers' Association stated that the blow-by device will be placed on 1961 automobiles to be sold in California. Secretary Fleming of DHEW testified that he could see no reason why the device should not be put on all cars on the assembly line.

* * *

Nuclear Energy

WASTES AT 'MINIMUM' FROM POWER STATION

The Pennsylvania Sanitary Water Board has commended the Duquesne Power and Light Company of Pittsburgh, for operating its Shippingport, Pa., nuclear power plant with a "minimum of hazard" to public health.

The Board commended the company for the low level of radioactivity produced in the daily operation of the installation, on the Ohio River below Pittsburgh, which is the world's first commercial nuclear power plant for generation of electricity.

When the Board decided to issue an industrial wastes permit for the Shippingport plant two years ago, it included a provision requiring a comprehensive report covering all phases of plant operation. The report shows the radioactive wastes produced are less than anticipated. The Board has since approved seven more radioactive wastes permits.

* * *

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EDITORIAL

Most engineers agree that with the increasing tempo of scientific and technological advances—often sparked by themselves—their academic background is little more than the beginning of education in their specialty. They must therefore keep themselves informed literally on a day-to-day basis. Just about the only handy "current events" text is the professional technical publication.

The suggestion that every engineer should consider the possibility of making a contribution of his own to this literature is a valid one. The objection

ASCE

Sanitary Engineering Division

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raised most frequently—"its not my business as an engineer to write, and anyway I don't know how and i've got no time!"—may reflect low professional morale, a sense of inferiority, and/or pure and simple intellectual laziness. At the very least, the inability or unwillingness to make a modest contribution to the literature cannot be a characteristic of the engineer who is proud of his calling, is glad of the professional company he keeps, and who is aware of the expanding horizons and strategic contributions his profession is making to society's welfare.



